TRANSACTIONS

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(INSTITUTED 1852.)

CHIMNEY FOR THE NARRAGANSETT ELECTRIC LIGHTING COMPANY, PROVIDENCE, R. I.

By JOHN T. HENTHORN, M. Am. Soc. C. E.

WITH DISCUSSION.

The chimney for the Narragansett Electric Lighting Company of Providence, R. I., was designed by the writer's firm (Remington & Henthorn) and built under their supervision. It forms a part of a large central station, which was in process of construction at the same time under the supervision of the same designers.

The location of the center of the chimney is 101 feet west of the harbor line of the Providence River, and the foundation, which was begun in August, 1888, formed part of a general contract for other portions of the station. This foundation consists of piling and concrete, and to arrange for it, a space 44 feet square was first excavated 5 feet 6 inches below zero line or high water, and the sides protected by driving 3-inch spruce sheet-piling 16 feet long. Over this excavation the pile-driver, having a ram weighing 2 200 pounds, was rolled. Spruce piles, 50 feet long, and spaced 30 inches center to center, as shown on Plate I, were driven as far as possible without breaking. There are, however, many more piles shown on this sheet, but these were driven

to sustain other structures alongside, and are, therefore, not to be considered as chimney-piles. In the drawing, the chimney-piles, of which there are 231, are shaded slightly that they may be more readily recognized. These piles were cut off uniformly at 5 feet below the high-water line, the earth around their heads thus being 6 inches below their tops. The intervening space between the sheet-piling was filled in with concrete composed of one part of Norton's hydraulic cement, two parts sand, and three parts coarse gravel and broken stone. This mass was carried up to the 1 foot 3-inch level, and consequently formed a foundation 6 feet 9 inches thick, with the head of each pile projecting 6 inches therein. This was then covered with earth and allowed to season during the winter.

On May 31st, 1889, work was resumed by laying the first brick of the chimney. This was carried up in the form of a square of 36 feet to a height of 3 feet 2 inches, and from that level the base of the chimney proper which was 28 feet 6 inches square, was started.

The center of the chimney was fixed by building into the brick-work a cast-iron plate, upon which was a well-defined center mark. From this center mark all measurements and plumbing were established while the chimney was being built. As each 20 feet in height was built, the center of its axis was re-established, and if any deviation from the plumb was found it was corrected before the next 20-foot level was reached.

The base of the chimney, which, as before stated, is 28 feet 6 inches square, consists of three walls: an outer wall 28 inches thick; an intermediate wall, octagonal in form, 12 inches thick; and a core wall circular in section 16 inches thick. The outer and intermediate walls are joined by pilasters 12 inches thick.

In commencing the base of what might be termed the core wall, each course of brick was set back $2\frac{1}{2}$ inches from the previous course until the inside diameter, 14 feet, was reached, when the wall was carried plumb 16 inches in thickness up to the 78 feet 2-inch level, where it was reduced to 12 inches, and run up to 193 feet 2 inches, when it was again reduced in thickness to 8 inches, and thus carried to 249 feet 9 inches. This wall complete was laid in lime mortar, which had been slaked from three to six months before using. The outer wall, of rectangular cross-section, was carried up to the 38 feet 2-inch level, where at each of the four corners cut granite blocks were placed, to change from a square to an octagonal cross-section.

This granite work is made up of three pieces in the lower course of 2 feet 8 inches in thickness, and two courses with one stone each, also 2 feet 8 inches in thickness. On the angular face of these stones was cut a triangular section or projection to relieve the monotony of a plain surface, and when in place they fulfilled their mission to perfection. Level with the top of this granite work and in the center of the panel of the octagonal side is laid a terra cotta brick belt course, which thus forms the commencement of the 24-inch pilasters at each of the octagonal corners, and leaves an intervening panel 4 inches deep of varying width, as the chimney is reduced in size by the batter. These pilasters are carried up to the 223 feet 2-inch level, at which point the first projection for the head is made, and from that point carried still further, on the same batter, up to the crown of the arches, which are then turned between the panels.

The outside wall, together with the intermediate wall and their pilasters up to the 38 feet 2-inch level, were laid up with cement mortar, one part cement and two parts of sharp sand, excepting the outside course of the outer wall which was laid in soapstone finish mortar, of a dark red color. From this level (38 feet 2 inches) up to the commencement of the head, 223 feet 2 inches, the outer wall was laid up with mortar consisting of two parts lime, and one of cement. For laying up of the head from the 223 feet 2-inch level up to the point to receive the cast-iron cap, one part of lime and one of cement were used, and for backing up underneath the cap after it had been thoroughly screwed together, three of sand and one of Portland cement was used. Special brick was used for the outside course at each of the corners of the octagon, which were moulded to shape in order to avoid cutting and at the same time secure a better outside finish. The bond throughout the entire structure consisted of full headers for every six courses of brick-work. This method of construction was carried on up to the 66-feet 2-inch level when work was suspended November 29th, for the season of 1889, and the top of the structure covered with matched boarding and tarred paper for the winter.

The chimney was built entirely from the inside platform, the masons working overhanded, and thus no staging was necessary on the outside.

Up to the level of the granite work all the stock used was carried up a ladder placed on the outside. But at this point there was constructed inside the 14-foot chimney-flue, an elevator, fitted with safety-clutches

and capable of carrying 1 000 pounds, although not more than 450 pounds was allowed to be placed upon it at any one time; and thereafter everything used in the process of construction was sent up on the elevator, to hoist which a nineteen-strand steel cable was used. The temporary framework inside the flue consisted of four 6 x 8-inch timbers, laid across each other at right angles, in pairs, and built into the wall at intervals of every 5 feet. Through the opening at the center, the elevator passed. Over these timbers was laid a platform of 2-inch plank, upon which the masons performed their work. To these 6 x 8-inch horizontal timbers, at opposite corners, were bolted the vertical guides for the elevator and the upright framing by which it was hoisted; these were spliced out at the top each alternate staging.

The opening for smoke flues is 10 feet wide and 18 feet high, with a 28-inch arch of 5 feet radius. The lower part of the opening is on the 14 feet 2-inch level. Directly below and above the opening on the 13 feet 2-inch and 33 feet 2-inch levels, were placed in each of the four sides of the chimney and 8 inches from the outside surface of the wall —two 1½-inch diameter tie-rods, with 1½-inch ends. These were all connected together by cast-iron corner-plates 12 x 14 inches square. Openings were left at each corner so that the nuts could be examined occasionally as the work dried out.

From and including the 53 feet 2-inch level, there were laid edgewise at each 20 feet in height and 8 inches from the outside surface of the chimney, wrought-iron bars of 4 inches x ½-inch, with their ends bolted together, forming an octagon corresponding to that of the chimney. At the 133 feet 2-inch and 153 feet 2-inch levels these braces were reduced in size to 3 inches x ½ inch, and were not again used until the 223 feet 2-inch level, or when the commencement of the head was reached, at which point bars 3 inches x ⅜ inch were bolted together in the wall. Their next application was in the head, where two braces made of 4 inches x ½-inch iron were used to assist in binding the heavy brick-work together during construction, which had considerable overhang (2 feet 9 inches on each side).

With reference to the outside wall, the outer and intermediate walls, with their connected pilasters, were built as one structure and terminated on the 83 feet 2-inch level, where by the batter of the outer wall it joined the intermediate and became one wall from that point. At this level two holes, 5 x 8 inches, were left in each of the eight sides

of the intermediate wall, so that the intervening space between the outer and inner walls might be ventilated, if by any possible chance gases should find access to this space. These ventilating holes are in communication with the space between the outer wall and the core, which is carried nearly to the top.

As before stated, work was suspended November 29th, 1889, and on April 22d, 1890, work was again resumed, but on account of bad weather it was thought well to hurry the construction along somewhat, so that June 28th four arc lights of 2 000 candle power, were placed upon the top of the elevator staging of the chimney for lighting at night, and a gang of masons relieved the day gang. This was continued until August 6th, 1890, when the night gang was dismissed, the chimney having then reached the height of 223 feet 2 inches. At this point the head of the structure was commenced, and gradually built up in cement mortar, as before stated, and measured when completed 24 feet across its sides; and on the 10th day of March, 1891, a flag was hoisted on its top by the eight-year-old son of a member of the firm of the designing engineers in honor of its completion, and in celebration of the visit of the National Electric Light Association, whose president, Mr. Marsden J. Perry, is also general manager and vice-president of the Narragansett Electric Lighting Company.

On October 4th, 1890, all brick-work was completed up to the 253 feet 9-inch level, and ready to receive the cast-iron cap, but on account of delays, the iron-work was not received to place in position until January 26th, 1891. On February 11th, the first of the twenty-five pieces of the cast-iron cap was hoisted to the top, and the work of bolting it together commenced. Copper bolts were used entirely for securing it together, these passed through flanges cast on the under side of the plate forming the cap. There were also on the outer surface upright flanges, one turning down over the other, and thus preventing water from penetrating the brick through the joints of the cap. This construction is plainly shown on Plate II. All of the joints of the cap where there was a possibility of leakage were carefully filled in with sal-ammoniac and iron borings, thoroughly rammed or calked in, and thus, as will be readily seen from the design of the joint (as shown in detail on Plate II), a perfectly tight and secure connection was obtained. The weight of the cap alone when in place was 22 000 pounds.
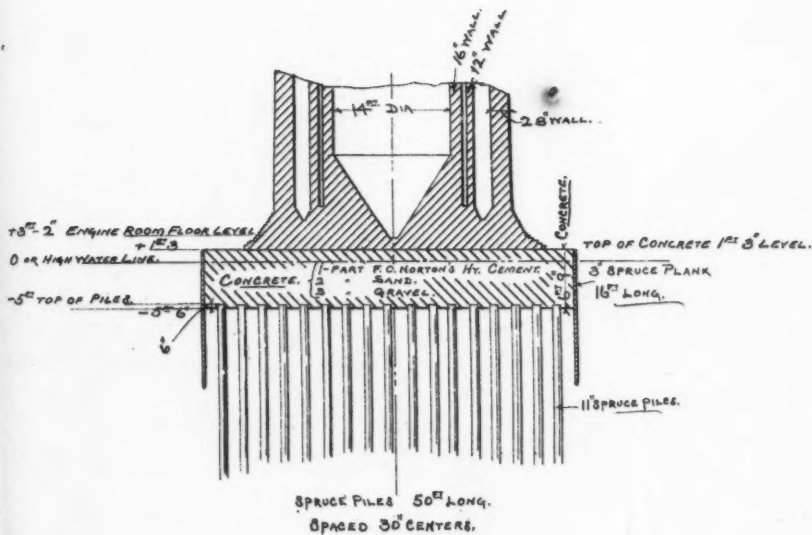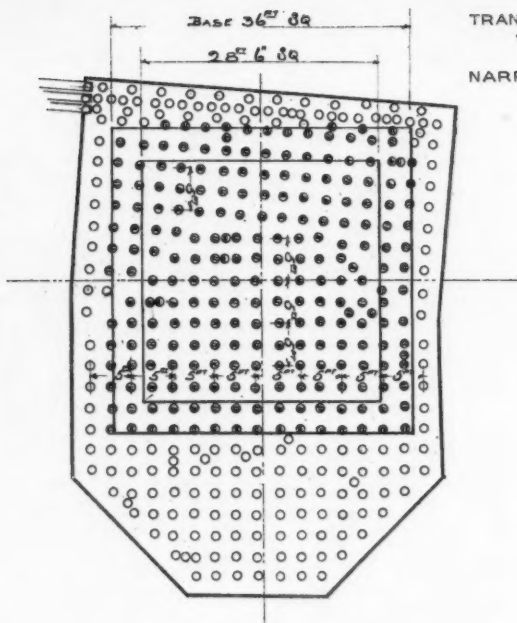
In order to facilitate ascending the chimney a ladder made of 1¼

round iron was built solidly into the outer wall at a point in its circumference where there was the greatest space between the intermediate and core walls; these bars were spaced 16 inches center to center, and as before stated were built into the outer wall, while in the core wall their ends were merely inserted into a cavity, 2 inches wide and a course of brick high, so that any expansion of the inner core would not affect the solidity of the ladder. Ascending this ladder, provision is made for protection from the gases at the top by building across the corner a cast-iron vertical plate, with its edges turned into the brickwork 8 inches and its lower end terminating at a point 3 feet below the top of the core wall, thus forming a chamber ; and from this, by means of a hatchway in the cap, also provided with ventilating openings in its side, access to the outside of the cap is readily had. Since the completion of the chimney this ladder has been used several times, not from necessity, but for the novelty of the deed on the part of workmen.

An attempt has been made to protect the structure from lightning by encircling the cast-iron cap with a copper ribbon $1 \times \frac{3}{16}$-inch thick, to which are connected by a riveted and soldered joint, eight brass upright sockets, one in the center of each panel of the cap. To these brass socket castings, are secured by soldered-joint, $1\frac{1}{2}$-inch seamless drawn copper tubing which extends upward above the top of the cap and conforms to its shape. After projecting 5 feet above the upper portion of the cap the tubes are each surmounted by a brass casting 28 inches long, tapering in cross-section and having at its extremity a platinum point $1\frac{3}{8}$ inches long. The encircling ribbon around the cap is connected with the ground ribbon by a brass casting thoroughly riveted and soldered thereto. As it runs down the chimney this ground ribbon is secured in position by brass clamps with bolts which were built into the brick-work as it progressed; this arrangement as a whole is shown in detail in Plate IV. The lower end of the ribbon, which is $1 \times \frac{3}{16}$-inch copper, rolled in one piece 285 feet long, terminates in a copper plate 30 inches wide by 60 inches long and $\frac{1}{16}$-inch thick, and is buried 4 feet below the natural level of the water in the soil of the premises. This plate is buried in a load of powdered coke, 18 inches being placed above and 18 inches in thickness below the plate, and the whole filled up with gravel.

After completion, the outside of the chimney was thoroughly oiled, in order to bring the brick-work to one uniform color.

BASE 36ᶠᵗ SQ

28ᶠᵗ 6ᶦⁿ SQ

16" WALL

12" WALL

14ᶠᵗ DIA

2 8" WALL

CONCRETE.

+8ᶠᵗ-2ᶦⁿ ENGINE ROOM FLOOR LEVEL.

+1ᶠᵗ 3

0 OR HIGH WATER LINE.

TOP OF CONCRETE 1ᶠᵗ 3" LEVEL.

CONCRETE. {1-PART F. O. NORTON'S HY. CEMENT. 2 - SAND. 3 - GRAVEL}

3" SPRUCE PLANK

16ᶠᵗ LONG.

-5ᶠᵗ TOP OF PILES.

-8ᶠᵗ 6

6ᶠᵗ

11" SPRUCE PILES.

SPRUCE PILES 50ᶠᵗ LONG.

SPACED 30" CENTERS.

0 2 4 6 8 16

SCALE OF FEET

+260 ft 9" ABOVE HIGH WATER.

7 ft

36"

+253 ft 9"

24 ft OUTSIDE

9"

22 ft 6"

4 1/2"

21 ft 9"

4 1/2"

21 ft

4 1/2"

20 ft 8"

4 1/2"

27"

+237 ft 2"

19" 6"

18 ft 6"

+223 ft 2"

12 ft 8"

27" — 27" — 27" — 36" — 36"

SCALE OF FEET
1"/5 ft

+253ᶠᵗ 9"

+207ᶠᵗ 2"

+223ᶠᵗ 2"

SCALE OF FEET

CAST IRON CAP TO CHIMNEY CORE.
COPPER BOLT
CAST IRON.

26'-9" ABOVE HIGH WATER.

INNER OUTSIDE 30'-0"
32'-6"
31'-0"
30'-0"
26'-5"

19'-6"

18'-6"

OCTAGONAL

TERRA COTTA BELT COURSE
GRANITE CORNER STONES

+ 46'-6" TOP OF STONES

+ 35'-6" BOTTOM OF STONES

SQUARE

+ OR HIGH WATER LINE.

Scale of feet

28'-6" SQ
36" INNER

6"
STONE

OCTAGON
15'-5½"

PARTIAL VERTICAL
SECTION SHOWING
JOINT FOR CAP AND
TOP TOGETHER.

MAN HOLE
COVER.

¼ COPPER
BOLTS.

2'4"ᶜᴰ

15'ᴱᴰ 3"

4"ᴱ 4½"

4"ᴱ 4½"

PLAN VIEW OF CAR

SCALE OF F

PARTIAL PLAN SECTION
SHOWING JOINT
FOR TOP TOGETHER.

PARTIAL VERTICAL
SECTION SHOWING
JOINT FOR CAP AND
TOP TOGETHER.

PARTIAL PLAN SECTION
SHOWING POSITION OF
CASTING "A."

PLAN OF BRACES BUILT
INTO WALLS OF CHIMNEY.
SCALE, HALF SIZE.

SECTION THRO. CENTER.

SCALE OF FEET.

DETAIL OF CASTING A

BRASS CASTING.

$8\frac{1}{2}"$

$10\frac{13}{4}"$

$\frac{3}{4}"$ TAP.
CHECK NUT.

$2\frac{1}{2}"$

$\frac{7}{16}"$

$\frac{5}{8}"$ BRASS BOLT.

SLOT PLANED $\frac{3}{8}"$

SOLDERED TOGETHER

$5\frac{1}{2}"$

$14\frac{1}{2}"$ LONG.

$5"$

$\frac{3}{8}"$ THICK

BRASS CASTING.

SCALE OF INCHES.
0 1 2 3 4 5 6 7 8 9 10 11 12

PLATINUM TIP

BRASS CASTING BUILT
INTO CHIMNEY WALL
EVERY 10⁻ᴲᵀ FOR
SUPPORT OF COPPER
RIBBON.
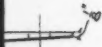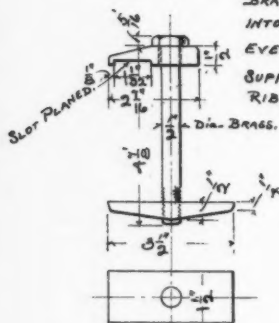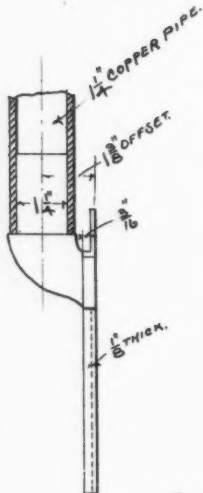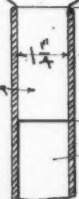
SLOT PLANED

½" Dia. BRASS.

1¼" COPPER PIPE.

1⅛" OFFSET.

⅛" THICK.

CASTING.

BRASS CASTING.

28"

SQUARE.

⁹⁄₁₆"

3¾" DIA.
BALL.

1¼"

3"

SOLDERED TOGETHER

1¼" COPPER PIPE.

8FT 1"
TO TOP OF CAP

OF INCHES.

PLATINUM TIP 1⅝" LONG

BRASS CASTING

1¼" COPPER PIPE.

COPPER RIBBON AROUND
CAP 1"x 3/16" TO WHICH ALL
POINTS ARE CONNECTED.

COPPER RIBBON 1" WIDE 3/16" THICK.

CONNECTED, AT BASE OF STACK, TO A COPPER
PLATE 30"x 60" BEDDED 4 FT BELOW WATER.

SCALE.—

5'-1"

8'-1"
TO TOP OF CAP
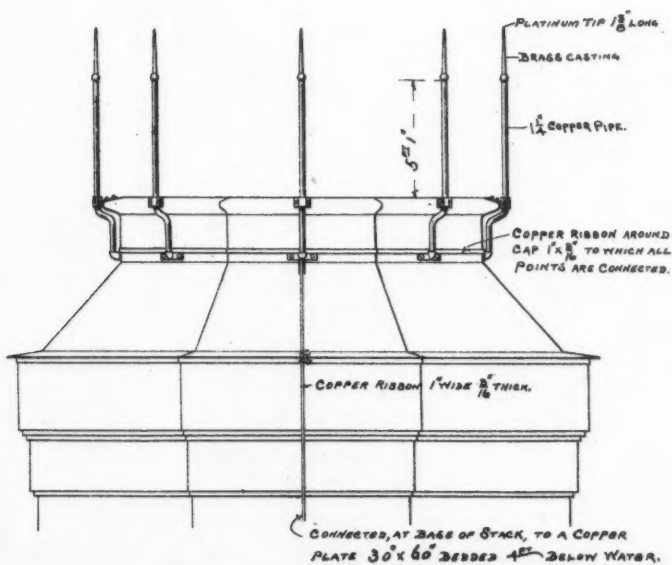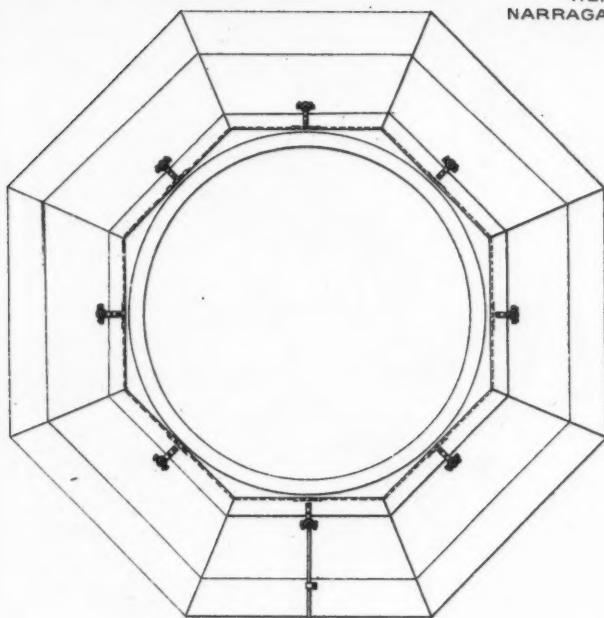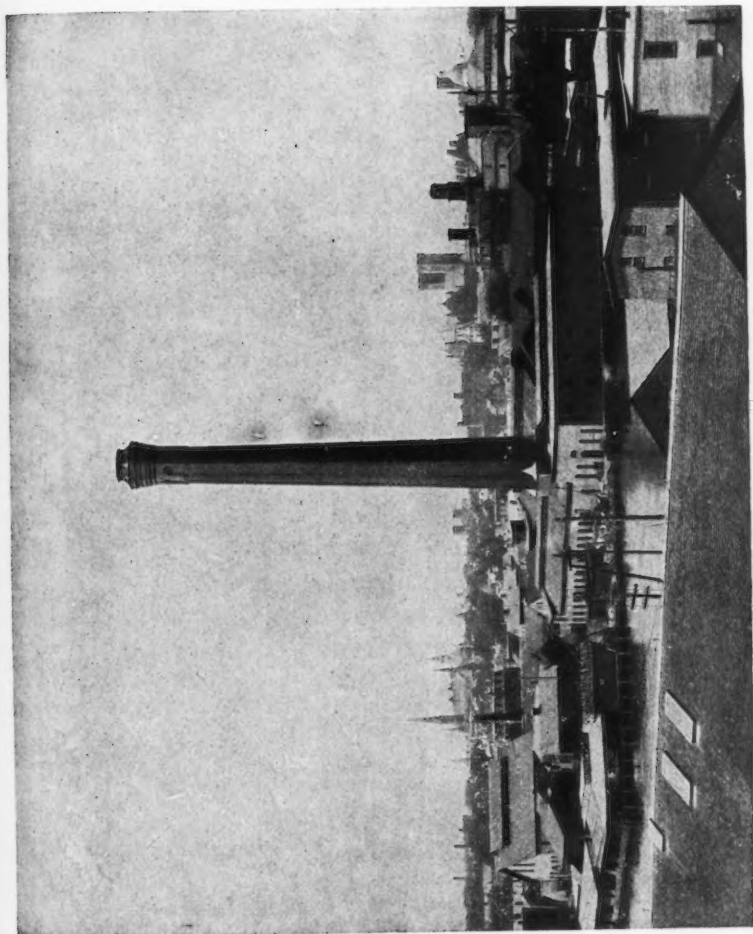
The amount of material used in the course of construction above the concrete foundation, is as follows:

> Brick...................................... 1 332 921
> Lime ....   695 casks.
> F. O. N. cement........................   1 025   "
> Portland cement.......................   17   "
> Soapstone coloring....................   99   "
> Sand ....   3 858   "
> Cast-iron cap.........................   22 000 pounds.
> Cast and wrought-iron.................   7 215   "
> Copper bolts   250   "
> Lightning rod and brass castings.......   326   "

With reference to the drawings which accompany the paper:

> Plate I shows a plan of the foundation piling.
>
> Plate II shows an elevation of the chimney, vertical and horizontal sections, an elevation of the head, and section and detail of the cap.
>
> Plate III shows details of cap.
>
> Plate IV shows detail of lightning rod construction.
>
> Plate V shows general view of chimney.

DISCUSSION.

CHARLES E. EMERY, M. Am. Soc. C. E.—I wish to testify to the skill and care shown in the preparation of plans and the execution of this work, and am much obliged to Mr. Henthorn for making a record of the matter in the transactions of the Society. The erection of a ladder between the shell and core is a novelty to me. It causes one to more fully realize that the core is the real chimney and that the remainder of the structure merely gives the core lateral stability. The suggestion arises, why not, in sightly locations, make the exterior portion a tower like that of a standpipe, with such openings as are desirable for architectural effect, and let the chimney proper stand up inside of it? I never have seen any philosophical reason for stopping the lining below the level of the outer walls. It would seem that the cap could be much better protected if not exposed to the action of the gases, and that the draft would be a trifle better if the flue were the higher.

THE FIRST TRIP THROUGH BIG HORN CAÑON.

By E. GILLETTE, M. Am. Soc. C. E.

So much has been written respecting our large cañons in the West that it seemed as though there was little left to be told. Having occasion last winter to examine the box cañon of Big Horn River, the writer was much surprised to learn that the cañon had as yet been unexplored. It may be safely stated that this is one of the latest, if not the very last of our large cañons to hold out against the explorer. This fact alone has induced the writer to consider his explorations in this cañon worthy of special notice. Through southern Montana and northern Wyoming the cañon has had the reputation of being impassable. Any one who would attempt its passage was considered not in his right mind, and a prospector who ventured part way down the cañon in a boat, was reported in the local press as surely lost. Scouts and hunters who had looked down from the rim of the cañon, had reported a depth of half a mile, with vertical walls, while the river was full of very steep rapids and falls. Taking advantage of the ice which had formed upon the river, the writer was able to make the trip by five days' hard travel.

The Big Horn River, above the head of the cañon, is over three hundred miles long, and drains an area of twenty thousand square miles. The drainage from this extensive section has cut its way through the limestone sag, between the Big Horn Mountains on the east and Pryor Mountains on the west, forming the formidable box cañon of Big Horn River.

On the morning of the 7th of March, 1891, with blankets for bedding, and provisions for five days tied upon a sled constructed of cottonwood poles, the writer started with an old Black Hills prospector, by the name of N. S. Sharpe, on my trip through the box cañon. The head of this cañon is 4 miles south of the crossing of the Montana-Wyoming boundary line, the balance of the 50-mile cañon being situated in the Crow Indian Reservation in Montana. Entering the cañon at the head, we found the river frozen to a depth of 3 feet, but as we journeyed downward, open water was encountered at nearly every bend of the river. The cañon almost immediately from the start rises to a height of 500 feet, with vertical walls. At the foot of these cliffs the talus extends from 25 to 100 feet, being at intervals washed away, leaving the cliff perpendicular to the water's edge. The talus stands at an angle of 45 degrees, and supports a growth of cedar trees which find root among the boulders. The cedar monopolizes most of the cañon, for no other trees grow here save a few cottonwoods at the mouths of side drainages and a scraggy pine or two near the mouth of the cañon.

As we journeyed down the cañon, keeping a sharp lookout for air-holes in the ice and glancing at the vertical walls of limestone on each side of us, we began to realize the fact that we were in the box cañon of the Big Horn River, the terrors of which had been so often repeated us to the measure that "no one had ever gone through the cañon alive." The talus being washed away at the entrance to the cañon as well as at the mouth, "no admittance" stares the pedestrian in the face, no matter from which end he may approach the gorge, and should he succeed in passing these gateways he would soon come to grief at some vertical wall extending to the bottom of the river, while the stream here is making good time down a rapid. This, probably, has prevented the cañon from being more thoroughly explored up to the present time.

Shortly after entering it we passed under overhanging cliffs which appeared to be striving to meet at the top. These cliffs extend over from the perpendicular 70 to 100 feet, and will form a shed, as the

boys said, "for a train of cars on a rainy day." There is ample room under the roof, as the shed towered hundreds of feet above us. Swinging around the bends of the river we soon came to the State line, where we found the balance of our party engaged in running a preliminary line in the cañon to determine its practicability for a railroad route. The men were apparently but a short distance above the river; however, when we had climbed up to them and looked down we realized that a tumble might result disastrously. We found the transit set up on the edge of a cliff with one leg of the tripod nearly parallel to the plumb line, while the transitman was barely able to maintain his position on the narrow shelving rocks; a misstep of an inch would have precipitated him to the hard bowlders 70 feet below. The chainmen made their way around almost vertical cliffs, hanging on with fingers and toes, and as we gazed at them we thought there is no room here for the fellow who usually "coons" a dangerous spot.

Taking observations on the height of the cañon we found the vertical wall to be 600 feet, while a slope of 45 degrees rises beyond, a distance of 200 feet more. This order of the cañon, with gradually increasing height, continues for 2½ miles, when we found ourselves at the entrance of Devil's Cañon, where the walls are 1 000 feet high, as determined by triangulation. As we gazed at the small patch of sky visible, and noted the smallness of the few trees up on the rim, we had a faint conception of the immense work the river has performed in cutting this channel through the mountains. The eastern drainage to the cañon comes from the Big Horn Mountains, while from the opposite side the streams drain the eastern slope of the Pryor Mountains. A peculiar feature of the Big Horn Mountain drainage is that these streams coincide with the divides, cutting their way through what appears the most difficult part of the country, completely reversing the position of the larger drainages in almost any other country. Devil's Cañon carries a stream of water from the new gold camp at Bald Mountain, and this stream, as if competing with the river, has formed a grand cañon of its own. Another feature of the cañon is, that immediately below the mouth of the larger side-drains the steepest rapids in the river occur. Tracks of otter, wolves, mountain sheep, and occasionally that of a bear, were noticed in the snow.

As we continued down the cañon the walls decreased in height, until at the Sentinel, 5 miles below Devil's Cañon, they are reduced to a

height of 500 feet. The Sentinel is a pillar of limestone, apparently 100 feet or more in height by 20 feet in diameter, and stands upon a point of rocks, 300 feet above the river. The writer named the rock, as the thought occurred to him that a sentinel might be imagined to be on duty protecting this beautiful cañon from disfigurement by some advertising agent. Had he with "pot and brush" endeavored to paint any of those well-known advertisements seen from any car window in the country, the writer is sure the sentinel would have fired upon him as an enemy to whom no quarter should be given. As night came upon us we went into camp beneath the Sentinel, well knowing we should find him on duty in the morning. From the Sentinel the walls of the cañon vary from 500 to 900 feet in height, vertical, as usual, and apparently no wider apart at top, than high. At intervals small streams break through the side walls of the cañon, forming formidable looking cañons of their own, while from the cliffs above, the smaller drainages, being too weak to cut their way through the limestone pour their waters over the cliffs, forming innumerable waterfalls 500 feet and more in height. At other places what appears a cave in the wall of the cañon is an outlet for some stream, which, having sunk in a recess back from the cañon, has tunneled its way through the wall, forming smaller cascades of from 200 to 300 feet high. Four miles below the Sentinel, the east wall breaks away, widening the cañon a half mile. Here is found a good ford of the river and a trail leading out of the cañon on both sides; this is about the only opportunity we found of getting into and out of the cañon for its entire length. Several good sized streams come into the cañon from the east side, above and below this ford, at the mouths of which gold is found in places, and this appears to be the case all through the cañon, as "colors" were found in every pan of dirt washed out, which had been taken from the bars near the mouth of these streams. At no distant day good placer mines may be found in this comparatively unknown cañon, and quartz mining back in the mountains will receive more attention. A short distance below the ford the cañon closes in again and continues thus for 15 miles, gradually increasing in height as the river approaches the main divide of the Big Horn Mountains. At 15 o'clock of this our second day's trip in the cañon we came to a most noticeable point of rocks, which the writer named, the Tower, from its form and commanding appearance. The west wall of the cañon is here pierced by a side drainage coming in nearly parallel to the main cañon, leaving a knife-edge or wall between

the two streams. This knife-edge is broken off vertically at the end, while a little distance back a square niche has been taken out of the edge 200 feet deep and long, leaving a pinnacle on the point towering 700 feet above the river, with an almost vertical slope on all sides. The Tower is one of the many picturesque points in the cañon, every bend of the river, however, reveals something new, and nothing commonplace is found throughout the entire length of the cañon. Four miles below the Tower we made our second night's stay in the cañon. Travel, so far, had been slow, owing to the depth of snow on the ice, and the numerous portages we were obliged to make around the rapids, where the river was free from ice. Three miles below this camp and 26 miles from the head of the cañon, there is a side drainage coming in from the west which splits a sharp point or angle of the cañon's wall, leaving a shell of rock on either side 500 feet high. This gulch is known by the name of Dry Hollow, and gold is found here in paying quantities. In several bars along the cañon and in places formerly the bed of the river, Sharpe panned out enough gold to show that the "diggings would pay."

Three miles below Dry Hollow Creek a sharp bend of the river forms a high sharp point of rocks, bearing down upon us from a height of 1 000 feet. This point, looking as formidable as the bow of an approaching steamer, has been named Steamboat Point.

Three miles from here Dry Head Creek, the largest drainage from the west, empties into the Big Horn, after having cut its way through the rocks and forming a cañon impassable for 6 miles back from the river. The walls of the cañon continue to grow higher as we work our way down, until at night, forced to camp on a shelf of rock, by an overflow of water on the ice, we gazed up at a cliff 1 200 feet high, and observed by the whirling snow up on the rim that a heavy wind storm was in operation, while there was a dead calm in the cañon. Starting out the next morning at 7 o'clock, we soon passed the mouth of Elk Creek, the third largest stream coming in from the Big Horn Mountains, and here we found immediately below the mouth of this creek a nice level tract of some 80 acres in extent. It is the only smooth ground in the cañon. As we approached Elk Creek the cañon began to widen out, and, rising in terraces, reached an altitude of over 1 000 feet. Here and there ragged points jut out into the cañon, capped with towers and pinnacles, and forming a castellated structure of surpassing grandeur and beauty for the next 10 miles, while the river is cutting its way through the divide. This divide

is passed 5 miles below Elk Creek. The lower part of the cañon here consists of a rough rolling country for 600 feet, covered with cedar and a few pines, then rising in broken terraces to the bare divide, more than a half mile above us. Startling a large band of mountain sheep, we watched these animals speeding along the terraces, jumping down short vertical cliffs in what appeared a most reckless disregard for the safety of life or limb, and they finally disappeared up one of the steep side cañons on a well-known trail.

Two miles below the divide, Black Cañon forces its way to the Big Horn, and duplicates the cañon of that stream as far as the eye can see. Just below the mouth of Black Cañon we came to the steepest rapid on the river, where the water at the present time is confined to a narrow bed less than 40 feet wide, the usual width being from 200 to 300 feet. The river continues narrow from here to the mouth of the cañon, and rapids are found at every bend. Innumerable warm springs pour their waters into the river, and we are forced, for want of ice, to abandon our sled and make the balance of the distance down the cañon, along the side of the stream.

We camped one more night in the cañon, among huge drifts of wood, 25 feet above the river, and can form a slight idea of how the cañon appears during the season of high water. The walls continue to maintain their lofty height down close to the mouth of the cañon. After a hard day's scramble over bowlders and cliffs we passed through the lower gateway at 16 o'clock, dragging our camp outfit behind us, as the ice here has formed sufficiently to barely sustain our weight. We have had enough cliff-climbing for the time being, and are willing to take some chance of breaking through the ice to save another laborious portage. Coming up on to the broad and fertile valley of the Big Horn, it was with a feeling of freedom and satisfaction we made our way down the valley and camp opposite the ruins of old Fort C. F. Smith. Having been confined for five days between those vertical walls of rock, we had no desire to make the return trip up the cañon, especially as of late the weather had been quite warm, and floating cakes of ice showed us that the river was "breaking up." This signified much to us, as it meant longer and more frequent portages. Congratulating ourselves that we at least had "gone through the cañon alive," we started back for camp, over the mountains, having first secured a little flour and bacon to replenish our now empty mess box.

We took the old Sioux trail going back; there was no fear of missing this route as the Indians have piled up thousands of tons of rocks to mark its course.   This trail which connects the Valley of the Big Horn in Montana with that in Wyoming has been used for centuries by the buffalo and Indian to avoid the big cañon of the river.   No Indian cared to venture into its depths and so this beautiful and comparatively unknown cañon has slumbered on for ages, awaiting the coming of the railroad for which it has cut a deep pass through the mountains, giving an easy grade for the transportation of the products of the country, besides revealing to the traveler probably the finest specimen of a box cañon in the world.   We enjoyed the scenery in an almost enthusiastic manner but could not help thinking that it would appear just as grand and beautiful from the rear platform of a Pullman, or from an observation car, as it did from amongst the boulders with a heavy pack upon our back.   After three days' wading through the snow we arrived in camp, in good condition to appreciate once more the blessings of full rations and a liberal supply of blankets.

In conclusion, the writer can state that the difficulty and danger of going through this cañon has been, as is generally the case in similar instances, very much exaggerated.   When the river is high it would be difficult and unsafe to go through the cañon.   Probably the best time of the year to make the trip would be in the autumn, when the water is reasonably low and boats can be used.   There are no falls in the river, and but few very steep rapids.   He would prefer making the trip in a boat, as in the winter, the ice being quite thin in places, one is liable to break through, when the swift current would take him quickly under the ice. We had an illustration of this above the head of the cañon.   A settler was leading two horses across the river on the ice, which suddenly giving way, precipitated both animals into the stream; the current quickly carried them away.

In a subsequent paper will be given a statement of the cost of constructing a railroad line through the cañon with the maximum grade and curve required, accompanying which will be a map and a few views of the prominent features and interesting points in the cañon.

DISCUSSION OF PAPER No. 444, "REDUCING INTERNAL WASTES OF THE STEAM-ENGINE."

By ROBERT H. THURSTON, M. Am. Soc. C. E.

I am able to add something to the collection of facts and data bearing upon this subject, as presented to the Society in the paper under consideration.

It will be remembered that the writer had endeavored to find a practicable way of reducing the heat-conductivity and the heat-storing power of the internal surfaces of the steam-engine cylinder, as had many before him, from the time of Smeaton and Watt, and he believed that he discovered that it would be possible to form upon these surfaces a non-conducting stratum, integral with the material of which they were composed, with the metal of the cylinder itself, that should intercept the heat tending to pass from steam to metal and to return from metal to steam after its temporary storage, in this manner, finally to be wasted as heat, and without transformation in any appreciable degree into work. This he had proposed to bring about by first, in any convenient and inexpensive way, effecting a partial solution of the superficial portion of the metal, leaving a spongy layer, consisting, as in the familiar case of "transformation into carbon," as it has been vulgarly supposed to be, of the interior of condensers and of channel-ways in condensing engines through the slow but extensive action of the passing stream of air-charged and hot water, from condenser to air-pump; then, by the im-

pregnation of this sponge with a resin or other non-conducting material produced by the painting of this surface with drying oil, or with any available substance that should thus be found able to permeate and cling to the porous surface.

In the paper presented to the Society it was stated that experiment had shown it to be practicable to reduce the conductivity of the surface to an important extent by simply adopting the first of these two processes; then it was shown that the second produced a still greater effect. Those experiments were laboratory experiments, made to determine whether the idea of the writer was correct, and whether the physical process and its results would be as anticipated.

This last question has been fully settled. It is found that simply oiling a surface capable of giving a good foundation and holding-power for the grease, will give a reduction of 10 per cent. in the heat-wasting power of the iron; that a very moderate degree of solution of the surface will, without other action, give a reduction of 20 to 40 per cent.; and we now find that the combination of the two processes described in the paper under discussion, gives a gain of 60 to 70 per cent., accordingly as it is more or less complete. We do not despair of securing so effective and so complete an action, in this way, as to reduce the heat-storing and wasting power of the metal of the cylinder to an insensible amount. It will then only be necessary to secure dry or moderately superheated steam to bring the efficiency of the real engine up approximately, perhaps sensibly, to that of the ideal engine; and thus reduce the consumption of steam and of fuel to substantially the figures to-day considered as purely hypothetical, and much below anything actually attained in the best of modern practice.

Experiments recently made on a small stationary engine (carefully adjusted until it did the best work in its history, and far better than when first set up) have shown a gain, in that case, of over 10 per cent. in expenditure of steam; though the treatment was superficial and only affected a depth measured in ten thousandths of an inch. These results have been duly reported to the A. S. M. E., by Mr. Royse, who carried out the investigation at my suggestion, and it is proposed to continue it on a larger scale. It may be presumed that, like the action of the steam-jacket, the effect of this treatment will be very variable with the size, character and conditions of operation of the engine to which it is applied.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

486.

DISCUSSION ON PAPER No. 465, PERMANENT EFFECTS OF STRAIN IN METALS.

By WILLIAM METCALF, M. Am. Soc. C. E.

Professor Thurston, in his reply to my discussion on this subject, unintentionally, no doubt, mistakes my remarks. He says (see Vol. XXIV, p. 186): "The brooming and splitting of bars, to which he refers," etc., etc.

I made no allusion whatever to the "brooming and splitting of bars," such bars could never be shipped to any person, nor could bars with the black core I mentioned be sent to any one safely, for their sure failure would lead to their return to the maker, as I learned to my cost before I discovered the nature and the cause of the trouble.

The weakness, brittleness, tendency to split, etc., that I mentioned, occur long before a black core is produced, and still much further away from "brooming and splitting."

As one illustration, take the section of a handy desk rule and paper cutter combined, which is much in use, and is made of thin steel. The center is bent to nearly a full circle, and from this the metal is bent sharply outward at each side so as to make the sides flare at about 120

degrees. This is not a very difficult bend for unstrained metal to endure. It is made a little over 12 inches long, and is bent up from a strip of cold rolled steel. No one who has not tried it can realize the difficulty there is in taking the finest and most ductile dead soft metal of not over 0.10 or up to 0.20 carbon, and rolling it barely enough to have a smooth surface, and yet have it endure that bend lengthwise of the bar. I could multiply instances by the hundreds if it were necessary. At the last we declined to make any cold rolled steel to endure a double bend, or a lengthwise bend except at a very high price, which was necessary to cover excessive cost.

It is quite common for people to order hundreds upon hundreds of short strips, say 2 to 3 inches wide, cut lengthwise across the grain from hot rolled sheets, so that when they are cut again into little strips, they will have the grain running lengthwise of the final strips. In many cases it increases the cost largely to cut sheets in this way, and I have suggested cheaper modes, only to be told that they knew what they were about and were willing to pay for what they wanted. As a rule, our shrewd manufacturers do not spend their money on mere fancies.

Yet we are told, "If a metal be subjected to a stress of any given kind, or in any stated sense," sufficient to produce permanent strain and set, then its ultimate resistance to that, or to *any other kind of stress*, will be sensibly increased, and in *all directions*, whatever the line of the deforming stress." (The italics are mine.)

The statement is not accurate, it does not cover all of the facts, and I regard it as dangerous.

In regard to Professor Johnson's remarks about the modulus, he clearly, did not catch my meaning, which was that the formula used for calculating springs based on the modulus of elasticity showed that any of the bars I mentioned, having the same modulus of elasticity, would make springs of equal capacity, whether tempered, untempered, annealed or not annealed—a manifest absurdity.

The bars were in three sets, consisting of low, medium, and high spring steel; they were all of the same size but treated differently, and yet all gave practically the same modulus of elasticity. The calculation was not mine, nor the conclusion, but eminent engineers have told me that the theory was right, only it does not apply to springs.

R. H. THURSTON, M. Am. Soc. C. E.—I have no doubt that I misinterpreted Mr. Metcalf's remarks about the splitting of his steel. On that

point he is an authority, at any rate, and I should not think of questioning what he has to say. As he now puts it, I see more clearly what he intends, and know that he is correct. My own statement, "If a metal be subjected to a stress in any stated direction, its resistance to stresses in other directions will be sensibly increased and in all directions," was exactly what I intended to say, and is precisely accurate in the sense in which it was intended that the words should be interpreted. I did not intend to say, and did not say, that if the metal were overstrained this would be true. We all know that a metal can be spoiled by overstrain, especially, in such cases as are referred to by Mr. Metcalf. My intended proposition is both justified and proved by the experiments described in that paper, and, I think, needs no further explanation. In those experiments, stress was applied in every principal direction, exceeding the elastic limit, but not going to the limit of incipient destruction, and, in every case the proposition was justified—as it has been by a thousand other similar experiments before and since the paper was presented, and as it always will be, I imagine, to the end of time. I do not think that it will be generally misunderstood. Stresses well inside the limit of rupture were, of course, intended and specified. In practice, they rarely much exceed the elastic limit; in the examples given in illustration, they were just above that limit.

J. B. Johnson, M. Am. Soc. C. E.—Mr. Metcalf seems to be laboring under the mistaken impression that theory indicates that the capacity of a steel spring is wholly a function of the modulus of electricity of the material. In his former discussion, he said, "I have a great respect for the modulus of elasticity, because since I worked it out as a student in Troy, I never understood its application in formulas involving all manner of strains." This statement is a sufficient explanation of the entire discussion on this point. If he had understood its application he never would have made his subsequent statements in regard to the failure in its application to steel springs.

The fact is there is probably no single function used in engineering formulas concerning which there is a closer agreement between theory and practice than in the case of the modulus of elasticity. It is now known that this modulus for all grades of wrought-iron and rolled steel, of all degrees of hardness, and of all stages of tempering, probably varies between 27 000 000 and 30 000 000. Any results obtained outside these limits are more likely to be erroneous than that the modulus

really has such values. The fact that poor observations have given us, even in standard publications, erroneous values outside these limits, is not to be placed to the discredit of the theoretical formula. But this is not quite Mr. Metcalf's trouble. He argues that because the modulus of elasticity was found to be the same for all grades and tempers of iron and steel, therefore they should theoretically have the same capacities when shaped into springs of equal volume. Of course persons who do understand the modulus of elasticity would not draw any such conclusion, and it is difficult to conceive that there are many " eminent engineers" in this country who would state that the theory of elasticity " does not apply to springs " within their elastic limits.

If a plain statement of some very elementary principles may be pardoned in this connection, it may be as well to say that the modulus of elasticity is simply a ratio between any given distortion (within the elastic limit) and the stress produced by it. It is an indication of the stiffness of the body. The higher this modulus, or ratio, the stiffer the material. Since wrought-iron has the same modulus as spring steel it has the same stiffness. That is, it will require the same load to deflect two similar bars of these materials the same amount, this amount being less than their elastic limits. This is not only a theoretical fact, it is constantly proved in practice. In fact the identity of their moduli of elasticity is only known from just such tests; and within the elastic limit of the iron, one bar is as good a spring as the other, as I took occasion to say, in my former discussion. So much for the stiffness of the two bars.

When we speak of the capacity of a spring, however, we may mean either the greatest static load it will carry and fully recover, or we may mean the greatest shock it will resist (absorb) without permanent set. In the former case, where strength only is involved, it is no function of the modulus of elasticity at all, but only of the maximum fibre stress (strength) which the material can resist without permanent set. In the latter case, where energy is to be absorbed, the capacity of the spring to do work (in foot-pounds) is a function of both the modulus of elasticity and of its elastic limit strength. Given two materials having the same moduli of elasticity, their capacities to absorb energy, or do work, will always vary, for all kinds and shapes of springs, directly as the square of the elastic limits of the materials. Thus, if a wrought-iron spring has an elastic limit of 30 000 pounds

per square inch, and a highly tempered steel spring has an elastic limit of 90 000 pounds per square inch, then the steel spring will have a capacity for resisting shocks of just nine times that of the wrought-iron spring of the same size and shape. There is nothing new or strange about this. Many elementary works on the mechanics of materials give all these facts, and the exact formula to use for any kind of spring. I would undertake to compute the maximum load, shock, or deflection of any standard style of steel spring from the theoretical formulas and obtain results very closely agreeing with any actual tests which might be put upon them. There is an impression abroad that there is an eternal conflict between theory and practice even in engineering. This I always deny. Any theory worthy of application is simply a generalization from actual experiment, or, it is generalized practice. Anything, therefore, coming from a high authority, which unjustly tends to deepen the prevalent distrust of wholesome theory in engineering, should, in my opinion, be immediately corrected, and nullified if possible.

Mr. METCALF.—Prof. Thurston's letter so modifies his paper that I think all will be clear now, he still exaggerates my position slightly, but that is no matter. I regret more than ever that he was not at Cresson to discuss his paper, then everything would have been cleared up more thoroughly and in a nicer way. It is a pity that we cannot always have good face-to-face discussions.

Replying to Prof. JOHNSON.—There is some danger that this discussion will become funny, or wearisome, and altogether unprofitable.

I repeat, I do not see how a modulus of elasticity obtained by stretching a piece slowly in tension, is going to furnish data for the computation of all sorts of shocks and vibrations applied all at once, producing torsion, extension, compression, deflection, and vibrations all in the same instant; this is what happens in springs. I may be wrong, I confess I never tried the computation, simply from want of faith; the party who did try it failed ingloriously; if Prof. Johnson can calculate the strength of a helical spring accurately, not approximately, he can teach the world something. I know the formulas, and I know about how closely they work. Professor Johnson says, "where strength only is involved it is no function of the modulus of elasticity at all." I agree with him entirely. I have made springs to other people's formulas involving the modulus of elasticity as an indicator of strength and I know just how near they were.

I am sorry Professor Johnson thinks I wish to belittle theory to exalt practice; I think his conclusion is hardly just, and I think if we could talk together ten minutes we would not find ourselves differing greatly. My whole objection is to the drawing of general conclusions, or laying down general laws, upon insufficient data; and since Prof. Thurston has modified the statement that led to this discussion, by saying, in all "principal directions," the addition of the word "principal" ends the discussion, as each person may give his own definition to the word principal, and the modification makes the statement no longer a general law. Finally, I hope Prof. Johnson will allow some weight to intelligent experience even when it is not backed by testing machine data, and that he will not confuse it with that ignorant practice which knows not its own ignorance, the most deplorable of all mental conditions.

TRANSACTIONS.

SECTIONS AND MECHANICAL CONDITIONS OF CAR WHEELS.

By P. H. GRIFFIN, Assoc. Am. Soc. C. E.

It is strange that the mechanical conditions under which car wheels are used have received so little attention from engineers and railroad men generally when the great attention given permanent way is considered. A vast sum has been expended in the past ten years in improvements of every kind calculated to make perfect road-bed. The subject has received more attention from engineers than any other connected with their work. Inducements of every kind have been held out to the men responsible for the maintenance of proper conditions. Inspections are regularly and constantly made. In fact the subject as a whole is well understood, and the possibilities and defects are thoroughly known. Ingenious appliances have been brought into use for detecting bad conditions, and the track that is not in nearly perfect condition to-day is so because of a lack of care, or from necessity not allowing the carrying out of work that is not questioned as to its value.

Almost equal attention has been given the matter of equipment. Heavier and more perfect construction has been followed, and everything that the best mechanical practice could suggest has been carried

out with a view to making cars and locomotives as well adapted as possible to the service in which they are used.

We have then, the highest types of mechanical construction in the the two great divisions of practical railroad work—permanent way and equipment. Between the two comes the car wheel; the one thing that must necessarily receive and transfer all of the load and power; the one active agent that enables motion, and supplies through mechanism operating upon it the only means of control over the enormous forces developed and used.

It would hardly be considered good mechanical practice to build a costly and perfect stationary engine and connect it with a heavy piece of machinery, also costly and perfect, devoting all possible care to both objects and little or none to the medium through which the power was transferred from one to the other. Yet in such a case all that could be considered would be loss of power and danger of accident due to imperfect conditions in the connecting parts. It would be only natural to expect that the care bestowed on the first two ms, costing, perhaps, one hundred times the third, would be proportionately given to the last one, and that the order of mechanical perfection would be equal in each part. Consider again, a case where the third part was possibly neglected and that every defect in it was multiplied thousands, yes, millions of times, with a direct result on the other two parts; that would be, as stated, a strange case; yet it is precisely what exists on all of our railroads to-day. What engineer can describe the section of car wheel best adapted to safety ? (We are now speaking of chilled wheels; the kind that is under 90 per cent. of the equipment in this country.) Who can say from actual knowledge how much the wheels under the cars of his company vary in diameter from each other on an average; or how much they are out of round or out of balance, or whether wheels of the same weight are placed on each axle?

It may be answered that of course such things must be right, or that it is not the province of the engineer to investigate such subjects; or again, that a small variation in these particulars is not important. Considered as a whole, good management in practical matters of the kind will embrace all conditions affecting every branch; if one is neglected, the results that might be obtained from the others are lost. Therefore, the subject is one in which a proper interest may be taken by all concerned in the construction, maintenance or operation of railroads.

As stated, 90 per cent. of the equipment of the country has chilled car wheels under it, and therefore the subject is determined mainly by wheels of that class. Of the comparative value of different types of wheels a few words will be said later on.

The matter will be presented under two heads:

First.—Proper Section and Methods of Manufacture.

Second.—Mechanical Defects, their Causes and Results.

The best section of wheel depends largely on the service intended · and upon the quality and character of the wheel, but certain lines should be followed irrespective of these two conditions on all steam roads.

The strains imposed on a wheel are of two kinds; the first consequent on load carried and speed attained; the second that which results from the use of brakes. The first strain multiplies the second in a definite degree. Given a speed of 20 miles per hour with a load of 5 tons per wheel, and a pressure of 50 pounds in a 10-inch Westinghouse cylinder giving 10 000 pounds pressure on each brake shoe. (You may note the diagram showing levers and pressures in Plate II.) One-half of this pressure applied for five minutes under the conditions named will develop through friction a certain amount of heat; the wheel must take up the heat and consequently expand. Just what strain is developed in the wheel during the operation is not easily determined, but it is over 100 tons. You will be able to compute the increase in strain at higher speeds and with greater loads or longer application.

As to extreme limits, they must be considered. On heavy grades it is common practice to carry double the load named, at double the speed and with double the continuous brake application; presumably each condition would double the strain. The last one, *i. e.*, heat developed by friction would increase it in a greater ratio because it would be a continually increasing condition.

It is not only necessary to consider in connection with this matter the speed proposed for general use or the loads intended to be carried, but it is absolutely necessary to consider the maximum that could possibly be imposed, and to provide a margin of safety beyond that. You provide for strains in other construction that are beyond anything met with in service. The same must be done in a car wheel if absolute safety is sought. You must also remember that in most construction only conditions under your own control are provided for. Suppose you were sending your bridges all over the country to be used by all sorts of care-

ful and careless people; or that you were taking all sorts of bridges and using them without particular investigation of their quality. That is impossible of course, in practice, but that is actually what is done with the car wheel, and if a man was given the choice of taking his chances for life and damage over a broken wheel or defective bridge, there would not be much choice. There have been more people killed and property destroyed with broken wheels than by defective bridges. So much for the need of a known basis to follow in the construction of wheels.

Plate I illustrates the New York Car Wheel Works' standard section of 33-inch 600-pound car wheel. As this style of section is followed in different weights and thickness of metal in all diameters, the explanation will apply to them all. It is, as you see, the regular double plate style of wheel known as the "Washburn" pattern. The section lines and curves, however, are peculiar to the standard named, and are based upon many years of practical and extended experience, as well as upon long continued and elaborate investigations into every feature composing the whole. A 33-inch wheel of this section with $\frac{5}{8}$ths-inch plates and of standard hub, bracket and tread dimensions, weighs 550 pounds, and is the minimum in this diameter for steam railroad service consistent with safety. Wheels are made to this standard in all diameters from 24 to 43 inches, and weighing 400 to 1 200 pounds.

In the figure shown, the hub section is calculated to stand a strain of 150 tons in pressing on the axle; this is more than double the pressure used. Wheels of heavier section are made to higher standards in this respect, the limit going up to 500 tons. The core dividing the double plate is made, as you will note, with a slight lip on the outer edge. It is common practice to bring the lines of the core at this point to an abrupt finish with the idea of making the metal at the junction of the plates heavier, and therefore presumably stronger. As a matter of fact, the opposite result is produced when this is done, for the greater body of metal remains fluid and soft a little longer at that point, and therefore, the shrinkage of surrounding parts is fed from it, leaving the metal porous and weak at the very place where it should have the most strength. To this cause is largely due the fine cracks found at the junction of the plates when wheels are subjected to continuous heat service. These cracks do not always go through the plates, often do not penetrate over $\frac{1}{2}$th of an inch, but they form starting points for more serious defects.

The core dividing the two plates is known as a "pan-core," because it is made in a dish or core-pan formed to the shape of the bottom of the core; the top is made with an iron sweep pivoted on a center hub in the core-pan. As per Plate II, "*a*" is the pan, "*b*" the hub, "*c*" the sweep; "*d*" indicates a ring set in the core-pan and used with a larger hub to give extra metal when a larger sized bore is wanted in the wheel. The use of these rings is very necessary, otherwise wheels are bored out for large axles with the consequence of leaving insufficient metal in the hub to withstand the strain. There should never be less than ⅝ths of an inch of metal in the wheel hub at the center of wheel seat—the thinnest point, after it is bored for the axle. The core is sustained in position on the mould by the legs "*e*" fitting into depressions in the wheel mould made by prints on the pattern.

"*F*" is a depression in the top of the core to receive the end of the chaplet which keeps the core in position. Cores are frequently used without this last provision, but it is very necessary, as it provides an extra quantity of metal in the form of a boss on the inside plate of the wheel, at a point where the iron chaplet is very liable to cool the hot metal quickly, and chill it for a space of ½ an inch or more around the chaplet, thus providing a starting point for defects. You will note that where the core-leg leaves a hole in the bottom plate, the latter is re-enforced by a fillet; this is very advantageous for the same reason as that given in the case of chaplets.

A great deal depends on the use of perfect pan-cores and upon the exercise of great care in every detail concerning them. When the best attention is not given, internal defects result in the wheel, very difficult to detect. If the chaplets are not exactly and firmly adjusted, one plate will be thinner than the other, and the metal consequently harder and weaker.

The bracket is 1⅛ inches thick at center and 2 inches deep. It fulfills two functions; the first to act as a runner or gate for the molten metal flowing into the tread, and the second to afford strength and support to the tread and flange in service. The section should therefore be determined by the area necessary to admit of the hot metal passing freely and rapidly to the flange and tread, and also by the dimensions best calculated to meet the expansion and contraction resulting from brake service. The bracket, as you will note, is curved to the radius of 5¾ inches inside, and 6⅝ inches outside. This is a very important feature.

As the hot metal is poured into the mould, brackets of this shape allow it to pass to the tread of the wheel with the least possible strain upon the casting, at a time when it has little or no practical consistency. It is vitally important that the metal be poured into the mould quickly and as hot and fluid as possible; this because of better homogeneity and soundness in the casting. In regular practice the metal should be cast into a 600-pound wheel in twelve seconds. As it takes with runners, head, screws, etc., over 650 pounds of metal to cast a wheel of this weight, you judge of the effect of practically dumping almost instantly nearly one-third of a ton of molten metal into a sand mould. Things have to be pretty nicely and perfectly adjusted to admit of that, and the circular bracket is one of the most important features in making it possible. The style of bracket generally in use is the ogee, or double curve. Presumably this style gives a better support to the tread, running at right angles to it. In practice, however, it is objectionable, for two reasons:

First.—In casting the wheel, the metal forming the tread flows through the brackets and strikes the cold chill forming the tread surface. It is thrown against the chill at a right angle, and must separate and pass to the right and left with many particles partially chilled or frozen, and with no chance for them to remelt and become homogeneous with the balance of the casting. It is almost impossible to pour metal as rapidly through brackets of this kind as through the single curved ones, because of the strain upon the casting when the mould is filling, or, to pour as hot metal, for the same reason. With the single curved bracket the pressure on the mould is not direct on its exterior; it is lateral all around.

Second.—In after service when the brakes are applied and the wheel expanded, the single curved bracket will adjust itself to the expansion and contraction better than the double curved bracket, and, consequently, prevent what is known as "cracked brackets."

The tread section shown has been considered by some too light. This is probably because of comparison with other patterns having heavy section at this point, to give an apparent solidity to the wheel. The uniform distribution of metal in the wheel is all important, and no greater mistake can be made than to add to parts which can be judged as to thickness and weight, at the sacrifice of parts the section of which cannot readily be ascertained. It is all important that the part of the wheel directly under the action of the brake-shoe be not of extra

thickness at the sacrifice of metal in the plates and brackets. All the strain is thrown on the latter and the greater the bulk of metal heated in the tread the more liable the wheel is to crack and break. Due consideration should be given these facts, and proportions followed that will provide against danger from every source.

The point of junction of single plate to tread is very important, chiefly on account of the effect of expansion from brake service. The contact of the brake-shoe is necessarily with the flat surface of the tread, and the metal in the flange acts as a preventive against expansion. When the single plate joins the tread too near the top of the latter, it forms in connection with the flange and brackets, a complete resistance to the expansion of the wheel. If it is kept lower down, when the tread is heated the top portion can expand and the whole casting can, if properly constructed, give a little without fracture; but when, as is sometimes done, the single plate is brought up near the top of the tread, there is, as stated, complete resistance at every point. That is not the way to prevent breakage. The old adage of the "bough that will bend, etc.," applies here with force. The single plate is sometimes brought near the top of the tread to prevent the latter "chipping" or breaking out, but trouble of this kind does not occur if wheels are properly and carefully made, and the practice is dangerous for reasons stated. Any style of chilled wheel can be tested for capacity to stand expansion from brake service by the following simple means: Lay it horizontally on the foundry floor; provide a sectional pattern that will allow sand to be moulded around the wheel and leave an opening ½ an inch wide all around extending from the throat to the edge of the tread. This may be quickly filled with molten iron from several small ladles, and the result is a band of hot metal ½ an inch thick and 4 inches wide, cast around the wheel. The effect is the same as that produced by a sudden and severe application of brakes. If properly constructed, the wheel should not crack in the plates with the application of the test. It causes a series of fine vertical cracks around the wheel and renders it unfit for service, but it may be used with entire satisfaction as to the value of results on wheels condemned for slight foundry defects. So much for the general details of construction.

It does not follow at all that good wheels will be made because a pattern of proper section is used. That is the first necessity; the second is the method by which the wheels are made. The manufacture of car

wheels is hard, laborious work. A first class moulder, if given a car wheel to make with ordinary foundry tools and appliances, would make possibly one or two for a day's work, and consider it a big day's work at that. Special tools and appliances are provided for the business, however, and one man with a helper will turn out on the average eighteen wheels per day.

The work is done almost invariably by the piece and is commenced and finished in ten hours or less. Half of this is given to moulding and the balance to casting. To prepare and finish eighteen moulds in five hours necessitates doing the work at the rate of one in less than twenty minutes. This does not afford much time for the proper carrying out of the many necessary and important details, and with workmen not very expert, many chances are taken for imperfect work.

The mould having been prepared, however, presumably in a proper manner, the quality of metal poured into it determines vitally the character of the wheel. On the preparation of the metal a few words may be said. The cupola is prepared and charged. If the metal is of good quality and strength and is properly poured into the mould all is well so far. But the most exacting attention to every detail is necessary in preparing and melting the iron. If not given, it may not always produce dangerous conditions, but it will not produce perfect ones. A chill test block 2 inches square by 6 inches long cast from the metal should have a chilled surface at least $\frac{7}{8}$ of an inch deep; this degree of hardness on the test will give $\frac{1}{4}$ to $\frac{3}{8}$ of an inch chilled surface on the wheels. A test bar 1 inch square by 12 inches long cast from the mixture should not break at less than 2 500 pounds when supported at the ends and loaded at the center; it should carry a load up to 3 000 pounds.

It is the practice of some wheel-makers to establish their results in this way by deductions from bars of different section and length, but on account of the decrease in strength due to extra hardness of small sections, deductions obtained in this way are unreliable. It is also stated by some that proper strength cannot be obtained in a bar of 1-inch section on account of hardness of metal. This is an excellent proof of the value of the 1-inch section when it is considered that the greater part of a wheel is less than 1 inch thick. If a proper degree of strength cannot be obtained in 1-inch bars how is it to be obtained in plates of less thickness in the wheels? It looks well, of course, to see great strength indicated on test bars of heavy section, but satisfaction as to

results obtained in that way is not all that could be desired. Any wheel-maker who cannot furnish test bars from his mixture, 1 inch square, that will carry 2 500 pounds load between supporters 12 inches apart, is not using a mixture that is what it should be; and if such bars will not carry 2 000 pounds the wheels are positively dangerous for use.

After the wheel is cast it is placed in the annealing pit. Properly speaking, car wheels are not annealed; they are slowly cooled for the reason that in the process of manufacture the outer part of the tread is cooled and set at a degree of heat lower than that existing in the body of the casting (this on account of the chilling process), and the entire cast-ing must again be brought to a uniform heat and cooled evenly. The cooling pits as they may be properly called, should be in dry ground. If dampness is found and steam is seen arising from the pits while the wheels are cooling or when they are being removed, shrinkage strains will certainly be found in the wheels and they will be liable to break in service. When such conditions exist they are always indicated by a reddish color on the wheels when cold.

We will now take up the second division of the subject: Mechanical Defects, their Causes and Results.

What engineer would consider for a moment the use of a track in which the following conditions existed? A rise or buckle of $\frac{1}{16}$ of an inch, and a curve in and out of $\frac{1}{4}$ of an inch in every 9 feet. Yet, as a mathematical proposition, what is the difference between running two wheels of exact diameter and pefect rotundity, fitted to an axle, over such a track as described, as against running two wheels $\frac{1}{8}$ of an inch out of round, and that vary in diameter $\frac{1}{16}$ of an inch, over a perfectly true track. The same rise and fall of the load must occur. The larger wheel would gain $\frac{1}{4}$ of an inch in every 9 feet, and it is manifest that it cannot continue gaining; it must be forced back or the smaller one pulled for-ward, or the wheels would not stay on the rail. You may think the con-ditions cited in the latter case are exaggerated, but, in fact, they are the minimum conditions of variation in wheels. The Pennsylvania Railroad specifications now under consideration for adoption by the Master Car Builders' Association accept wheels that do not vary more than $\frac{3}{32}$ of an inch from a true metallic ring placed over them. To place such a ring over a cast surface, not tooled, would certainly take $\frac{1}{64}$ of an inch all around, making up $\frac{4}{32}$ or $\frac{1}{8}$ of an inch. All things considered, to make castings weighing $\frac{1}{4}$ of a ton and over, true to $\frac{1}{16}$ of an inch to center as they come from the foundry, is remarkably good practice.

On the question of variation in diameters, $\frac{1}{16}$ of an inch is a very low average. Not alone the original, but the condition after service must also be considered. To keep a driving belt in the center of a pulley the casting is turned crowning at that point, and the belt stays there under every condition. The tighter it is put on and the more power transmitted, the more difficulty found in running the belt off the center. It is exactly the same with a car wheel. The highest point, or rather the greatest diameter will lead until an excessive condition forces it back to begin the same labor over again. The apparent result of all this is readily seen. Cars sway and jolt as they run. Far less than they did, of course, when the track as well as wheels was imperfect; but still they do it proportionately. The real result is more difficult to appreciate; but considered from a single arithmetical and mechanical standpoint it is evident enough in its magnitude.

The load on a wheel is, say, 5 tons, the speed 30 miles per hour, the variation in diameter from its mate $\frac{1}{16}$ of an inch—diameter 33 inches. The larger wheel will gain three and one-third times $\frac{1}{16}$ of an inch at every revolution. It will revolve six hundred and eleven times and would travel, if it could, 10 feet more in every mile than the smaller one. Of course, it cannot do that; the flange would not permit it; but it gets on somehow, pulling and hauling, grinding and wearing, carrying its heavy load all the time with probably nearly as much power wasted in overcoming defective conditions as would be required to do the real work if proper ones existed.

Again, take the matter of balance. Take the very low estimate of 5 pounds as the amount each wheel is out of balance; I have seen wheels five times that amount out. At 30 miles per hour a 33-inch wheel revolves three hundred and six times per minute. Fifteen hundred and thirty pounds must be swung around the circle described by its circumference every minute on every wheel under each car (eight wheels), therefore 12 240 pounds must be swung around every minute; on thirty cars 367 200 pounds or 184 tons must be moved that often. What power is required to swing 184 tons around a 33-inch circle once a minute for three hundred and twenty minutes—the time it would take such a train to run 100 miles. Remember this calculation has nothing to do with the motion of the train; when that is considered fresh questions arise. What effect does it have on retarding motion?

It may be said that the support of the wheel on the rail counteracts

to some extent lack of balance, but there is ample margin for all possible allowance that way and still have a remainder that is rich in possibilities. The precise nature of these results would be exceedingly difficult to get at by computation; it could only be determined by actual test of perfect conditions as against ordinary ones. The larger wheel unquestionably leads at all times, and the smaller one necessarily draws behind. The greater the load and higher the speed the more certain an extreme condition of this kind will prevail. With the flange grinding the rail instead of running free, power is wasted and undue wear occasioned. It is difficult to locate loss of power or rail wear caused in this way in specific cases, but when the car wheel speaks the whole story is told. Flange wear is the leading cause of wheel failure to-day in every type of wheel, and it has grown in exact proportion to the increase in load and speed.

These are not mythical propositions. We may content ourselves, as the boy did who carried grain in one end of the bag and stones in the other, simply because that had always been the practice. Or we may rely on some unknown law of compensation to make up for such conditions. As a railroad man once told me (not an engineer, I am glad to say), the cars had a certain amount of motion anyway, and these things all equalized themselves when the weight and the work happened to be off one or another particular spot.

There is no mystery about what constitutes good mechanical practice in other things. If you go through your shop and find shafting out of line, pulleys mounted out of center, or vibration in both, due to lack of balance in the pulleys, you stop it at once. It is bad practice—dangerous work. Your shaft revolves perhaps two hundred times per minute—a pretty good speed for shafting. Your pulleys, say 33 inches in diameter, weigh 300 pounds. If they are a couple of pounds out of balance, $\frac{1}{16}$th of an inch out of true; if your line shaft is out of true $\frac{1}{16}$th of an inch in every length, you would not assume the responsibility for that sort of work many minutes and expect safety or economy as a result. But you accept car wheels revolving three hundred to six hundred times a minute, weighing twice as much as the pulley, and from 2 to 20 pounds out of balance, and you do expect safety and economy as a result. You could not mount a pair of wheels taken from under a car in the heaviest bearings and revolve them five hundred times a minute. Leaving all considerations of load carried, tons of brake pressure applied,

and the multitudinous conditions of service, aside, and dealing with the
simple fact of running the wheels in fixed bearings at that speed, it
could not be done, simply because they are out of balance. You would
not stand around at close range when it was being tried, either. But
you put them under a passenger car and repeat the same conditions, or
greater ones, with little thought of consequences. Centrifugal force
and power required to do work under one or another condition have no
different cause or effect in either case. There is the question of the
difference in result given by the pulley as against the car wheel, when
it is considered that one runs on a fixed center and the other on a mov-
able one, as well as being supported on its periphery. But when it is
remembered that the car wheel does many times the work of the pulley
the results can not be much different.

Whether it is possible in railroad service to obtain in the beginning
and maintain in practice perfect conditions of this kind is a simple me-
chanical question. What the result would be if it were done cannot be
exactly stated because it has never been tried, but it is no unknown field
to work in; there is no experiment about it. If it cannot all be accom-
plished at once it can at least receive a share of the effort made in other
and similar directions.

Ten years ago we made car wheels as many makers do to-day.
Bought good material, used the best of care and conducted the whole
matter as a foundry business. But seven or eight years ago we intro-
duced methods that gave a little better information as to the quality of
each wheel; the practice of finding that out in service was not exactly
satisfactory.

It would take too long to follow the work up in all its stages; how
one thing led to another, and so on. But some six years ago the point
was reached where a definite system covered every wheel made as an in-
dividual thing. This, of course, mainly concerned the wheel as it came
from the foundry. It was possible to know whether each one was of
proper quality and to have full information on that matter. In the
effort to improve, the mechanical features of the question were opened
up and followed, until to-day the wheel leaves the foundry perfect as it
can be made there. But not to go to the railroad shop to have, perhaps,
fifteen minutes spent in putting a hole through it and pressing it on an
axle as the sum total of preparation for the most arduous mechanical
work known. It goes to the machine shop, where it is bored out, turned

absolutely true and balanced. Many say that this is unnecessary and useless work; that it decreases the life of the wheel; that the skin (?) on the chilled surface is the vitally valuable thing that must not be touched by the maker; that a difference in diameter is of no particular account; and that as to rotundity and balance, perfect castings can be turned out of the foundry. The writer has spent nearly twenty years in the foundry; learned the trade and worked at it for years; is fairly well posted in what is theory and what is practice. If the machine shop has no part in the preparation of a car-wheel for a service many times more severe than any other mechanical one, there can be little value in all the other details of mechanical work carried on there. The writer has yet to find any wheel-maker who has had a proper practical experience in the foundry say that wheels can be cast mechanically perfect. No doubt in certain instances with perfectly new tools, chills, etc., and special effort to produce the best result, castings can be made far more perfect than the average. But what about every-day practice ? Chills do not always remain new; ordinary workmen must sooner or later attend to the details. Is it possible to expect a good general result from conditions that will only produce it under special treatment that cannot be given in every case ?

So long as this question is determined by foundry practice alone and wheels are used as they come from the foundry, it is certain the conditions necessary will not be obtained. It is necessary to find a true center and finish a wheel from that in a mechanical manner to obtain a proper mechanical condition. One of two things will certainly have to be done. Railroads will have to adopt steel wheels, for the mechanical work on which they seem willing to spend hundreds, yes, thousands, of dollars, where they question that many cents to obtain in chilled precisely what they seek in steel wheels, or, they will have to turn and balance chilled wheels. They are progressing step by step to heavier loads and higher speeds; they are forced to. They are equipping freight cars with air brakes. For what? That cars may carry more and run quicker. It is one thing to apply the brakes on a car which, with its load, weighs 30 tons, and runs at 30 miles an hour, and have a brakeman do the work of transferring the power of one man through a $1\frac{1}{2}$-inch brake-mast, with a leverage of 6 to 8 inches from center; and it is another thing on a train running at double the speed, with double the load, to put at the command of the engineer on a train of thirty cars a power of 50 000

pounds per car for instant use. Think of it! If the air brakes are in proper condition on such a train the engineer has stored up in the air tanks under the cars a total force of 750 tons available for instant use. It will probably make some difference under such conditions whether wheels are round or balanced. It is making the difference now.

The best wheel is the one that will not break, that is mechanically perfect and that will retain its original conditions for the longest time. We have proven to our own satisfaction that the chilled wheel can be made to fulfill these conditions, and have a total of 600 000 in every kind of service without one case of breakage, as proof of possible safety.

One-sixteenth of an inch chilled iron will give more wear than six times that quantity of steel found in any steel tire. It must be remembered that steel tempered and hardened into cutting tools and steel not so treated are very different things, and that the latter condition is always the one found in steel tires. Furthermore, the life of a steel wheel in the severe service of to-day is not all in the flat surface of the tire; it is largely in the flange. To provide proper flange thickness on many steel wheels, from 20 to 40 per cent. of the tire must be turned off and thrown away.

At best it is difficult to say what the entire result of the imperfect conditions referred to are in the practical operation and expenses, but as a conservative statement, based on long and careful investigation of the subject, the writer believes that with mechanical conditions such as they should be and such as can be maintained without difficulty on chilled wheels, the cost of power operating traffic carried over them can be decreased from 15 to 20 per cent. The cost of wheel service can be decreased from 25 to 50 per cent., and the saving in wear on equipment and permanent way will be in like proportions.

On the wheel subject generally a few words may be said. We have not studied and worked at it from the one standpoint of chilled wheel manufacturers, but have obtained all the information possible on the manufacture and use of the different types of wheels in all countries and on the results obtained from them. You will find in the appended table a very complete and interesting statement of results obtained from steel wheels in Germany during the past five years. It is instructive to those who consider steel wheels as the only proper thing for safety. It is right for railroads to investigate and try different articles to find out what is the best, but on this wheel question the practice is too largely

based on opinion, private and public. Railroad managers are so anxious to consult the latter that they say, as some of them have said to me, "We use steel wheels because if anything happened to one we could say we had bought the best." Why the best? Because the most expensive? That is one way to look at it; but on such an important item of expense as steel wheels it is quite important for them to know that they are practically as well as theoretically correct in their opinions.

A large consumer of steel wheels said to the writer that it took an average of two hundred per month to keep up his equipment, at a cost of $10 000 per month or $120 000 per annum, not to mention the cost of many lathes for re-turning the tires or the cost of the work; and yet he had more breakages of steel wheels than he ever had of chilled wheels in like periods. He said that if it were not for "public opinion" he would go back to chilled wheels. Well! Consulting public opinion at a cost of $120 000 per annum for a cause he personally did not believe in, could not be very satisfactory business.

There seems to be some inexorable law that ties some purchasers of chilled wheels down to a price that would not buy common iron castings, and that compels them to hold all wheels of that class as of one value and quality. Thirty-three-inch wheels, weighing 600 pounds, are sold commonly to-day for prices that do not net the maker eight dollars, freight and other expenses considered—a net price of $1\frac{1}{3}$ cents a pound. The best car wheel iron cannot be bought for such a price, and just how the purchaser expects the manufacturer to furnish fuel, merchandise of all kinds, plant, labor, and the general expenses of the business, and produce a good article, is a hard question to answer. Fortunately all wheel buyers do not follow such a practice, but so many do that the others think a dollar or two more should produce something extraordinary, when as a matter of fact they pay more per pound for their brake-shoes than they do at the highest price for wheels. If improvements in this matter are to be made, it must be considered from all standpoints and the same influences brought to bear upon it that have produced the highest type of modern engineering—the modern railroad.

The "connecting link" must be made as perfect as the parts it connects.

STATEMENT OF STEEL TIRES BROKEN ON RAILROADS OF GERMAN EMPIRE IN YEARS 1884 TO 1889, INCLUSIVE.

Years	Cast Steel On hand and in use.	Cast Steel Broken No.	Cast Steel Broken Per Cent.	Fusion Steel On hand and in use.	Fusion Steel Broken No.	Fusion Steel Broken Per Cent.	Martin Steel On hand and in use.	Martin Steel Broken No.	Martin Steel Broken Per Cent.	Manganese Steel On hand and in use.	Manganese Steel Broken No.	Manganese Steel Broken Per Cent.	Bessemer Steel On hand and in use.	Bessemer Steel Broken No.	Bessemer Steel Broken Per Cent.	Other Steel On hand and in use.	Other Steel Broken No.	Other Steel Broken Per Cent.	Puddle Steel On hand and in use.	Puddle Steel Broken No.	Puddle Steel Broken Per Cent.	Number of Steel Tires on hand and in use.	No.	Per Cent.
1884	106 838	259	0.24	197 573	298	0.15	53 922	52	0.10	1 635	...	...	380 189	834	0.22	6	...	...	201 682	1 410	0.70	941 945	2 853	0.30
1885	94 365	370	0.39	221 212	464	0.21	66 848	107	0.16	1 464	6	0.41	402 140	1 206	0.30	302	16	5.30	173 381	1 378	0.79	959 642	3 549	0.37
1886	96 099	294	0.31	189 688	500	0.26	93 694	177	0.19	2 039	...	...	453 857	1 771	0.39	244	32	13.0	157 615	1 214	0.77	992 636	3 988	0.40
1887	99 708	267	0.27	129 292	301	0.24	171 370	169	0.10	1 767	17	0.96	471 030	1 399	0.30	214	28	18.08	134 615	780	0.58	1 007 996	2 964	0.29
1888	92 203	348	0.38	115 617	380	0.33	204 932	241	0.12	1 419	18	1.20	510 925	1 908	0.39	170	68	40.0	115 887	821	0.71	1 041 135	3 874	0.37
1889	64 359	174	0.27	140 635	311	0.22	284 815	241	0.08	1 251	...	...	510 985	1 909	0.37	440	63	14.8	100 456	680	0.68	1 102 941	3 380	0.31

NOTE.—Plate I is a part section and a view of the 33-inch 600-pound car wheels manufactured at the New York Car Wheel Works at Buffalo.

Plate II shows the "hub" and "sweep" for the same, and also the strains in the various portions of the Hodge system of Brake Levers.

Plate III shows the arrangement of the mould for a 33-inch wheel.

33-inch 600 lb. Car Wheel.
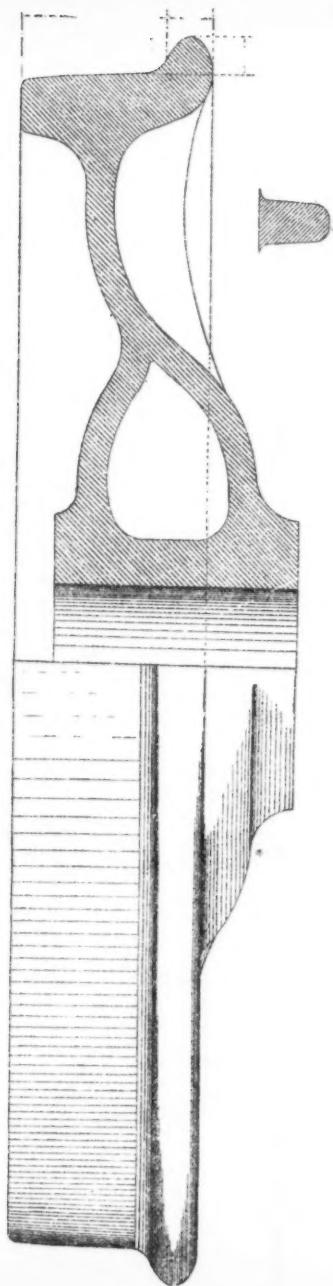
33=inch Core Pan,

33=inch Core Pan,

HUB AND SWEEP.

THE HODGE SYSTEM OF BRAKE LEVERS.

4,000 LBS.—GIVES TOTAL BRAKE FORCE OF 40,000 LBS.
4,700 LBS.—GIVES TOTAL BRAKE FORCE OF 47,000 LBS.

10 INCH CYLINDER
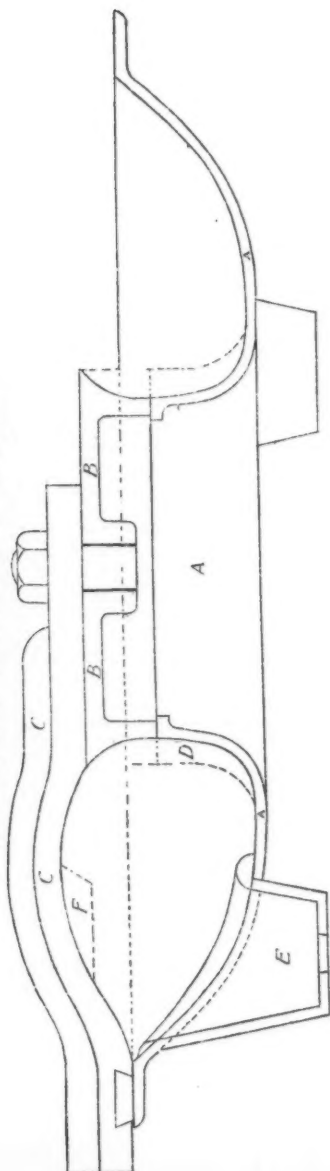
50 LBS.
60 LBS.
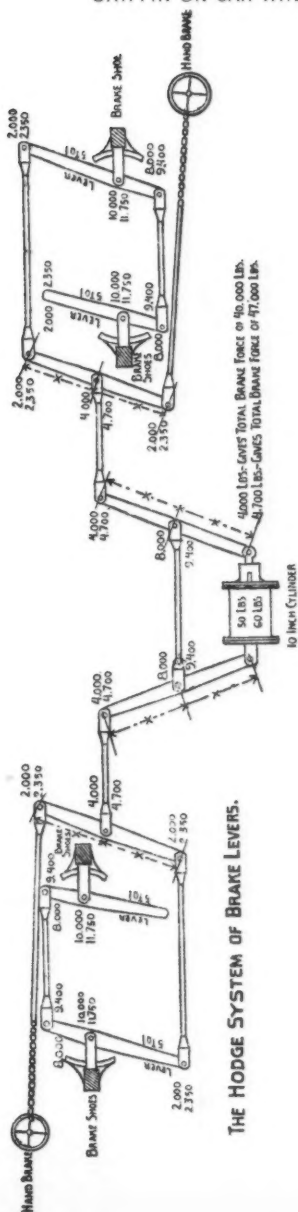
33-in. Chill, Cope and Nowel,

SHOWING PATTERN IN POSITION.

RUNNER HEAD OR DISH

SPRUE

SPRUE

CORE PRINT

CORE PRINT

CORE

CORE PRINT

CHAPLET

PAN CORE

CORE PRINT

NOWEL

CHILL

BOTTOM BOARD
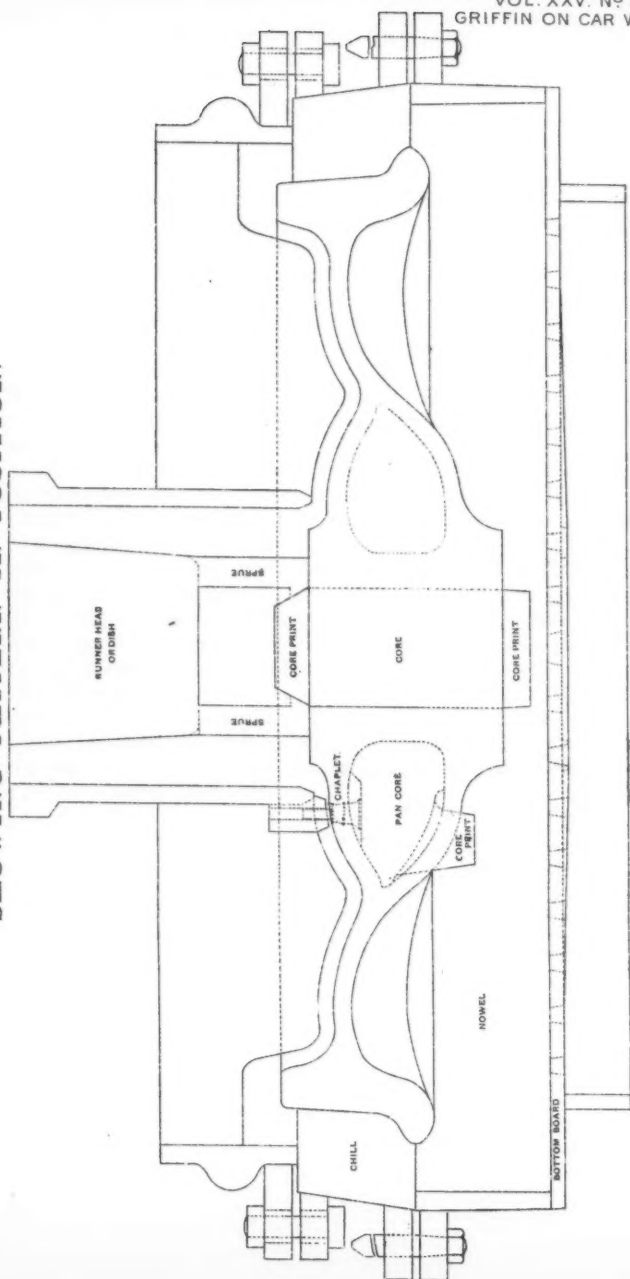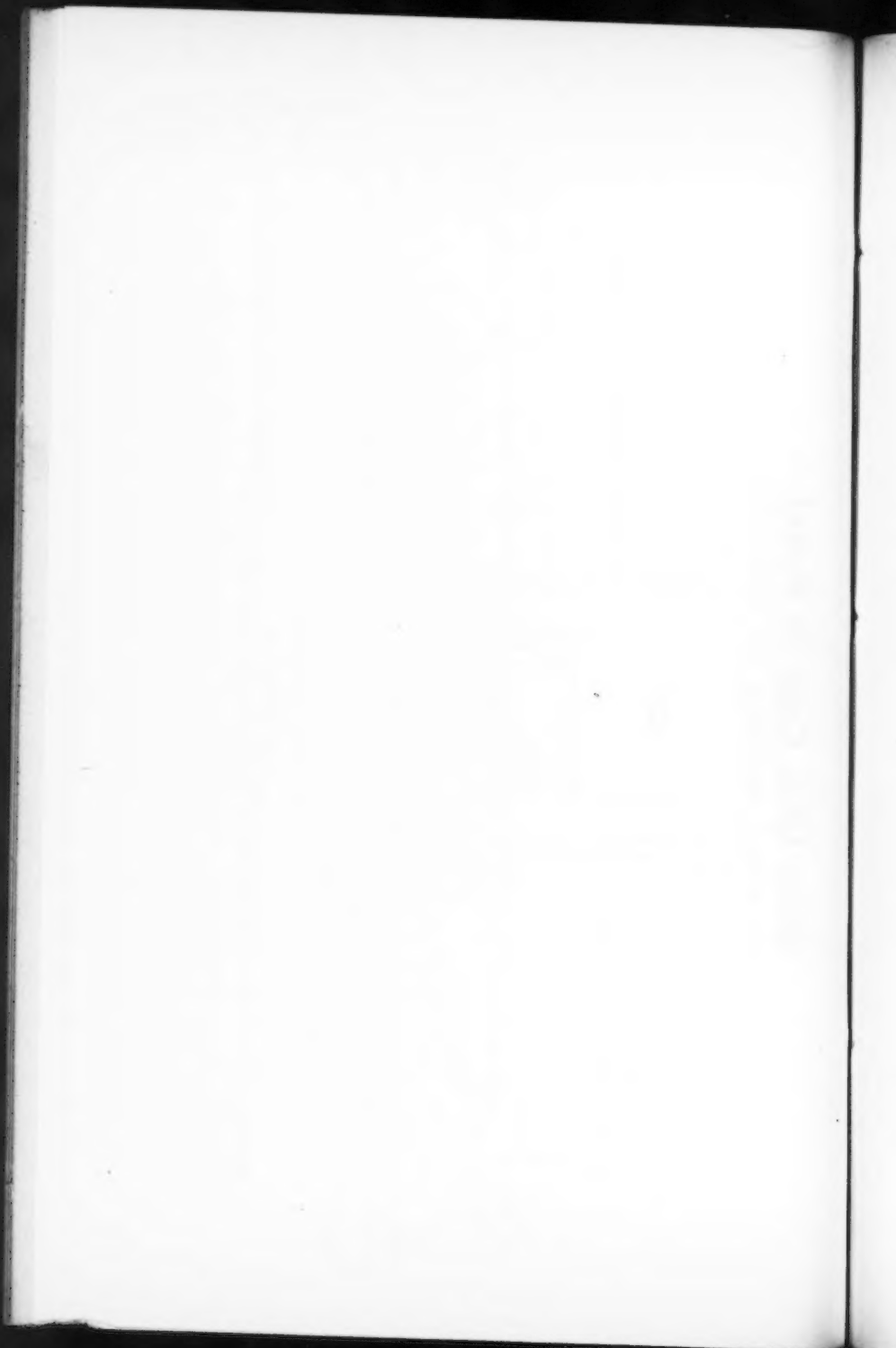
DISCUSSION.

GEORGE B. NICHOLSON, M. Am. Soc. C. E.—Mr. President, I think we have all listened to that paper with a great deal of interest. The author has given some very valuable information that I have not hitherto had access to ; I shall take pleasure in studying it. There is one question I would ask—if it is in the paper I did not catch it—to what depth does the chill go in the car wheel ?

Mr. GRIFFIN.—I said in the paper, the depth of chill in wheels is five-eighths of an inch.

Mr. NICHOLSON.—In turning down wheels that are brought to the shop how much of the original five-eighths inch chill can we safely afford to lose ?

Mr. GRIFFIN.—You would be safe in turning a ½ inch for such a wheel.

Mr. NICHOLSON.—Half an inch. That question was suggested to me some months ago by a gentleman who had a patent process for turning down wheels in which he claimed to produce a second chill ½ inch in thickness. In his process of turning down a wheel he produced by friction a heat on the surface.

Mr. GRIFFIN.—The chilled surface on a car wheel is caused by the sudden contact of the hot metal with the cold chill, and the result is due to the instant combination of carbon and iron at that point. Therefore, the chill is originally produced by the application of cold. The application of heat restores the metal to its original condition and destroys the chilled surface. There is no such thing possible as producing a second chill by any process that does not re-melt the iron and produce a repetition of the original conditions.

A MEMOIR ON WATER METERS.

By JOHN THOMSON, M. Am. Soc. C. E.

WITH DISCUSSION.

That there shall be no misconception in respect of the scope of this paper, it seems necessary to amplify the above caption by saying that it is not, nor does it pretend to be, an exhaustive technical treatise upon the subject of water meters, but is to be taken within the measure of its title, that is to say: the recital of personal knowledge and experience, with illustrations, tables, data and opinions, having direct and collateral relation to the development of the present state of the art.

The more one has to do, and the more intimate he becomes with the water meter question, the more certain is he to be astonished at the amount of capital, persistent thought, time and labor that have been expended upon this branch of hydraulic engineering; which is well exemplified in the patent tables herein submitted, showing, with approximate exactness, the number and designation of United States and British patents that have been issued for inventions in water meters. Thus it will be seen that from 1837 to the close of 1890, a period of fifty-three years, the United States Patent Office granted 678 patents in this class; while from 1824 to the close of 1889, a term of sixty-five years, Great Britain granted 231 patents, or a grand total in America and Great Britain combined of 909 patents. It is estimated that about 250 meter patents have also been taken in France, Belgium and Germany.

Among the most interesting deductions to be made from these patent tables are that about 50 per cent. of the total number of patents in the United States were issued during the last fifteen years; while about 50 per cent. of the total number of British patents were issued during the last twenty-two years.

Although it is probable that, say 10 per cent., of the grand total of patents are for the same inventions, still the figures are more probably under than over the actual, as the class comprising ships' logs and speed indicators has not been searched, not to speak of the analogous classes in pumps and engines.

NUMBER AND DESIGNATION OF UNITED STATES PATENTS, ISSUED FOR INVENTIONS IN WATER METERS, FROM 1837 TO 1890, INCLUSIVE.

YEAR.	ROTARY.	PROPORTIONAL.	PISTON.	OSCILLATING.	DIAPHRAGM.
1837......	....	....	....	....	1
1850......	1				
1851......	1	....	1		
1852......	1	....	2		
1853......	....	....	2		
1854......	....	....	2		
1855......	....	....	3	1	
1856......	....	....	1	1	5
1857......	1	....	1	2	1
1858......	2	....	....	3	1
1859......	3	1	1		
1860......	....	1	1		
1861......	3	....	3	....	1
1862..♠..	2	....	3	1	1
1863......	....	1	2	....	1
1864......	1	....	1		
1865......	3	....	3	1	
1866......	....	....	4		
1867......	4	....	8	2	1
1868......	9	....	13	6	2
1869......	12	1	17	9	3
1870......	14	....	16	5	2
1871......	14	....	28	7	5
1872......	8	....	15	5	2
1873......	6	....	4	2	1
1874......	11	1	7	1	3
1875......	7	2	5	....	5
1876......	10	1	10	4	1
1877......	10	....	8		
1878......	8	2	9	2	1
1879......	7	....	6	1	3
1880......	6	1	3	3	
1881......	4	1	9	2	
1882......	5	....	10	6	
1883......	7	....	6	1	3
1884......	5	2	10	7	
1885......	10	4	12	6	5
1886......	11	18	11	5	
1887......	11	2	11	2	1
1888......	13	....	8	3	
1889......	8	3	4	3	1
1890......	11	1	2	4	
Total..	229	42	262	95	50

Grand Total......................................678

NUMBER AND DESIGNATION OF BRITISH PATENTS, ISSUED FOR INVENTIONS IN WATER METERS, FROM 1824 TO 1889, INCLUSIVE.

YEAR.	OSCILLAT-ING.	PISTON.	PROPOR-TIONAL.	YEAR.	OSCILLAT-ING.	PISTON.	PROPOR-TIONAL.
1824....	2			1869....	....	16	1
1835....	1			1870....	....	4	
1840....	1			1871....	2	12	
1841....	1	1		1872....	1	1	
1842....	1	2		1873....	1	2	
1849....	1	4		1874....	....	6	
1850....	1	1		1875....	1	6	1
1851....	2	1		1876....	1	10	
1852....	....	8		1877....	....	4	1
1853....	....	3		1878....	....	8	
1855....	1	2		1879....	2	8	1
1856....	1	2		1880....	4	4	
1857....	2	4		1881....	....	8	
1858....	2	1		1882....	2	3	
1860....	1	4		1885....	2	3	1
1861....	....	4	1	1886....	2	6	
1862....	1	3		1887....	1	7	
1863....	....	1		1888....	1	7	1
1864....	1	2		1889....	3	3	1
1865....	....	1					
1866....	....	4					
1867....	1	7					
1868....	1	6		Total.	44	179	8

Grand Total.. 231

The first patent for a water meter was issued in the United States in 1837, for a diaphragm meter, but it was not until 1850, or after a ·lapse of thirteen years, that the second United States patent in this class was issued. In the following year, 1851, the third and fourth United States patents in this class were issued, both to the late Captain John Ericsson, Hon. M. Am. Soc. C. E., one for a double piston meter and the other for an inferential meter. The positive uncompromising character of Captain Ericsson is well illustrated in the expressions that appear in the latter patent, wherein the operation of the devices is predicted with such a degree of certainty as might have been applied to the law of gravitation.

Of the five United States patents issued for water meters in 1859, and only about the fortieth in sequence, one was to Mr. B. S. Church, M. Am. Soc. C. E., for a rotary meter.

The first British patent for a meter, No. 4982, of A. D. 1824, is designated a "fluid meter," but it is more properly a gas meter. It has had but little influence upon the art, yet the title of its inventor may be here recorded, which is as follows : William Pontifix, the younger, of

Shoe Lane, in the City of London, coppersmith and engineer, sends greeting:

British patent No. 8393, of A. D. 1840, to John Hanson, in a meter for "gas, water and other fluids," shows a piston-valve, contained in a cylinder, and has an exterior sleeve and chamber connected to the cylinder, in a manner practically identical with the "piezometer connection" shown by Mr. John R. Freeman, M. Am. Soc. C. E., in his paper on the "Hydraulics of Fire Streams."* Whether Mr. Freeman reinvented the device (as he probably did) or adopted it, in either case' its selection is equally creditable to his skill or to his judgment.

One has not far to look for a portion of the motive which preceded the applications for these patents, as it is found in the growing belief, held by many hydraulic engineers and water-works officials, that there is but one entirely satisfactory and just method of selling water to committees or individuals, which is by measurement of quantity; that it wou.d, in its results, be equally illogical and unsatisfactory to sell gas, bread, or medicine by *pro rata* tax as it in fact usually is when water is so disposed of. Nevertheless, it has only been for a short period that any actual record has been readily obtainable capable of showing what has actually been accomplished in the introduction of meters; and which at the same time, is in the nature of a demonstration of the commercial possibilities for the future.

The accompanying tables of meters and taps, compiled from the latest and most reliable data, show the surprising fact that the total number of water meters in public use in the United States, is but 124 798. But from a careful, conservative estimate, and considering the claims of the several meter manufacturers, it is probably safe to say that at 'ast 175 000 water meters have actually been made and sold in this cu itry. The discrepancy between the writer's estimate and the published returns, is undoubtedly due to the difficulty and often the impossibility of obtaining replies from water-works officials; to "wear and tear;" to private ownership, and mayhap to the asserted tendency of meter makers, like pump, engine and bridge builders, to tack on a unit now and then to their enumeration.

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* Transactions, 1889: Vol. XXI, page 303. November, 1889.

TABLE SHOWING BY STATES, AND IN TOTAL FOR THE UNITED STATES, THE NUMBER OF TAPS, THE NUMBER OF WATER METERS, AND THE RELATION OF METERS TO TAPS. COMPILED FROM THE *Engineering News* PUBLISHING COMPANY'S "MANUAL OF AMERICAN WATER WORKS, 1889–90."

STATE.	Number of Taps.	Number of Water Meters.	Percentage of Meters to Taps.
Maine	19 515	320	1.63
New Hampshire	14 076	1 403	9.96
Vermont	8 638	466	5.39
Massachusetts	221 610	24 912	11.24
Rhode Island	24 315	12 899	53.00
Connecticut	49 071	959	1.95
New York	410 236	30 219	7.36
New Jersey	96 408	6 608	6.85
Pennsylvania	337 040	1 263	0.37
Delaware	12 363	11	0.09
Maryland	74 165	835	1.12
District of Columbia	23 489	14	0.06
Virginia	23 140	185	0.80
West Virginia	9 991	5	0.05
North Carolina	1 940	381	19.62
South Carolina	1 067	22	2.26
Georgia	11 391	2 646	23.20
Florida	2 970	514	17.30
Alabama	7 306	1 000	13.70
Mississippi	1 250	9	00.72
Louisiana	4 660	20	0.42
Tennessee	15 748	432	2.76
Kentucky	23 361	1 311	5.61
Ohio	101 708	4 789	4.70
Indiana	23 623	822	3.48
Michigan	63 185	1 042	1.65
Illinois	154 966	4 897	3.16
Wisconsin	21 786	470	2.15
Iowa	19 281	1 691	8.25
Minnesota	12 114	466	3.82
Kansas	17 160	768	4.47
Nebraska	10 707	786	7.34
South Dakota	2 120	58	2.73
North Dakota	1 423	219	15.40
Wyoming	1 028	152	14.75
Montana	1 454	26	1.79
Missouri	57 182	4 056	7.10
Arkansas	3 538	131	3.70
Texas	19 675	1 303	6.62
Colorado	15 191	226	1.49
New Mexico	1 208	17	1.41
Washington	5 828	106	1.82
Oregon	8 745	106	1.21
California	77 954	16 103	20.68
Arizona	1 145	108	9 43
Nevada	4 425	20	0.45
Utah	3 393	1	0.03
Idaho	520	1	0.20
Total Number and Relation in United States	2 023 109	124 798	6.168

TABLE SHOWING THE NUMBER OF TAPS, THE NUMBER OF WATER
METERS, AND THE RELATION OF METERS TO TAPS IN THIRTY-ONE
OF THE PRINCIPAL CITIES OF THE UNITED STATES. COMPILED FROM
THE *Engineering News* PUBLISHING COMPANY'S "MANUAL OF
AMERICAN WATER WORKS, 1889–90."

CITY.	Number of Taps.	Number of Water Meters.	Percentage of Meters to Taps.
Albany	14 682	52	0.35
Augusta (Me.)	800	0	0.00
Atlanta	2 466	2 286	95.30
Boston	74 554	3 520	4.72
Buffalo	32 650	115	0.35
Baltimore	68 000	791	1.16
Brooklyn	82 217	2 137	2.60
Chicago	136 267	3 278	2.40
Cincinnati	33 082	1 304	3.94
Cleveland	27 516	1 644	5.97
Charleston	1 000	20	2.00
Denver	5 000	20	0.40
Detroit	31 821	50	0.10
Fall River	4 412	3 138	71.10
Hartford	5 984	345	5.85
Harrisburg	8 200	200	2.45
Jersey City	20 456	240	1.18
Kansas City	10 436	1 000	9.58
Louisville	11 001	678	6.17
New York	180 060	18 211	10.12
New Orleans	4 178	18	0.44
Nashville	4 496	15	0.34
Newark	19 854	501	2.54
Pittsburgh	17 681	45	0.25
Philadelphia	172 604	267	0.15
Providence	13 643	8 094	59.30
Richmond	9 606	85	0.88
Rochester	21 000	1 800	8.59
Springfield	5 147	556	10 90
San Francisco	30 000	12 750	42.50
Washington	23 489	14	0.06
	1 072 242	63 174	5.885

Now, divide the number of meters by the years of patent monopoly,
say, forty, and we will find an average yearly sale of about 4 400, al-
though it is not overlooked that from 80 000 to 100 000 of these meters
have actually been sold during the past ten years, or an average of from
8 000 to 10 000 meters a year during that period. This fact alone would
indicate a very rapid growth in sentiment favorable to the introduction
of meters. Yet, taken from even its most favorable point of view, this
is certainly not in itself such a showing as would be likely to so impetu-
ously lead on the usually, largely expectant inventor.

Let us, however, refer to the other columns of the table and we will
see that the total number of taps, or separate house services in the United

States, is 2 023 109; that, therefore, the relation of meters to services is nearly as but 6.2 meters to 100 taps.

In the table of thirty-one cities, the unexpected fact is brought out that the relation of meters to taps is less than that of the country at large, a result exactly contrary to what was anticipated.

After due consideration of the foregoing, it will probably at once be apprehended wherein lies the commercial incentive to the engineer to produce a meter of which he probably predicates in advance—in the glow of his youthful enthusiasm and self-confidence—that it shall be capable of successfully meeting the most exacting criticism; shall even be better than the best, and consequently will be certain of an introduction and sale equal to that residual of unserved taps which even yet amounts to the very substantial sum of 1 898 311 of the meter services of the United States.

The subdivision of the class of water meters, as it appears in the records of the Patent Office, is of but little value in an engineering sense, and must often be as misleading and troublesome to the office as to its clients. In the broadest sense there are but two types of water meters, those embodying the positive displacement principle and those embodying the inferential. By positive displacement is meant the successive filling of a chamber and the displacing of the fluid therefrom by mechanism capable of being acted upon by pressure, as in the instance of a cylinder and piston. By the inferential type is meant any device, as a current wheel, turbine, worm, or gauge, capable of being operated by, or in any manner responding to, the dynamic action of fluid; and which thus infers the total quantity, not by measurement of bulk but by lineal velocity or by pressure. Each of the foregoing types is properly subject to many subdivisions, and such a table might be here submitted but for the fact that established usage would nullify any value it might possess.

In respect of the drawings herewith incorporated, acknowledgment is only due to a collection of "meter literature," the gathering of which has extended over several years, consisting of trade-catalogues, detached plates of "proceedings," United States Patents, "Reuleaux's Kinematics," etc., of which free use was made both by direct transposal and by tracing. The several illustrations have been most carefully selected; the aim being to make a fair representation both of the growth and of the present state of the art, but without undue amplification of space and detail.

Thus in Fig. 1 the novelty consisted in the spring, e, acting upon the blade, d, ensuring end contact against the perimeter of the cylinder. It is
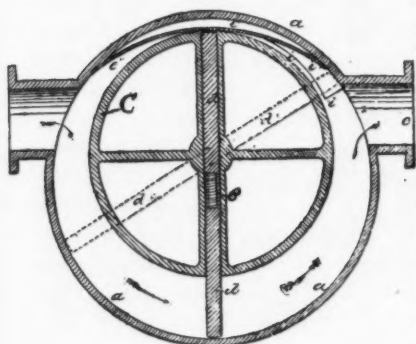
representative of a class of movements that have been variously modified, upon which many United States and foreign patents have been issued, but has never reached any commercial importance, except to absorb considerable capital in useless experimenting. In fact this same device, but in better and more practicable form, was patented prior to this by Woodcock,

Fig. 1.

in England, about 1840, while within the last decade it again came to the fore, hailing this time from the State of Pennsylvania, and it is said that about $50 000 was expended to ascertain that, although an old descendant, it was not a survival of the fittest. The device has the serious defect of combining small displacement capacity with large area of obstruction, that is the revolving block, C, which is mounted upon pivots. Hence, if the apparatus be reduced to compact dimensions, a high rate
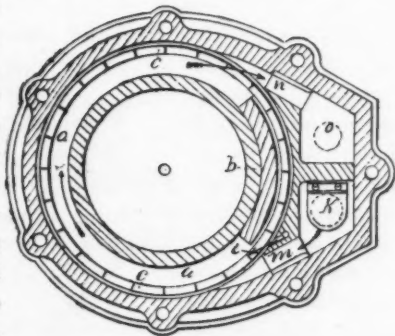
Fig. 2.

of discharge soon destroys it, in that the entire sum of the pressure, caused by the obstruction, is transmitted to and is borne by the pivots.

In Fig. 2, two novel features are presented: First, the loaded flap valve, K, in the main inlet chamber, causes a jet, i, of high velocity to impinge against the vanes, c, to start the "paddle wheel" at low rates of discharge. Second, the waterway, which follows around the semi-

Fig. 1.—Positive Rotary Meter. U. S. Patent of W. Sewell, February 5, 1850.
Fig. 2.—Inferential Rotary Meter. U. S. Patent of Capt. John Ericsson, Dec. 9, 1851.

circular chamber, *a*, entering and leaving it tangentially on the same
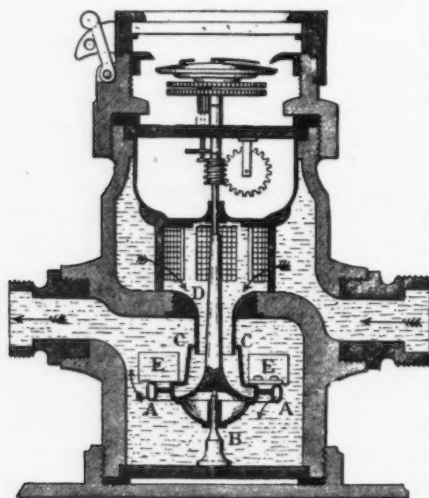
Fig. 3.

plane. Many modifications of this device have been patented, but it has had little or no practical application in the United States.

In Fig. 3 is shown a detail sectional view of Siemens' inferential reaction meter. This was an adaptation from the old Barker Mill, or "Scotch Turbine." The object of the wings, *E*, is to act as a brake, causing increased resistance and decreased speed of revolution at high rates of flow. Fig.

4 also shows a Siemens' inferential meter, but of the direct impact, or "paddle wheel" type.

Tylor's inferential meter, Figs. 5 and 6, Plate IX, of the direct impact type, presents several modifications over that of the Siemens', notably in the method of discharging the water radially from the vanes and in the same plane, as in Ericsson's. The screw, *F*, is for the purpose of increasing or decreasing the speed of the fan by controlling the size of

Fig. 4.

the jet; which acts in a direction opposite to the revolution of the paddles
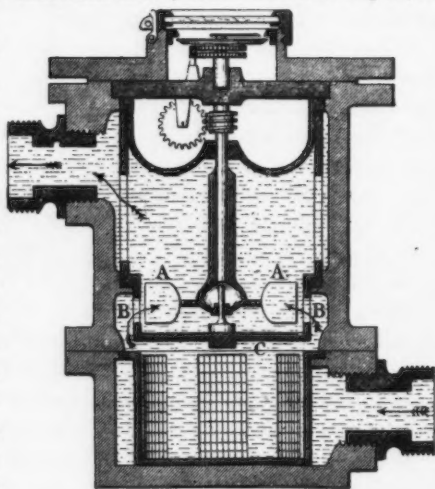
Fig. 3.—Siemens' Reaction Meter.
Fig. 4.—Siemens' Direct Impact Meter. Vertical center sections of the Reactive and Impact types. Manufactured and very extensively used in Great Britain and Europe.

B, and by which means the register may be properly rated. A recent improvement in Tylor's meter consists, as shown in the detached details, in twisting the blades of the paddle-wheel or fan in opposite directions; thus forming the wheel from one part, and overcoming the tendency to thrust upward or downward, which would otherwise exist if twisted in one direction only. It is common practice to fill the reservoir, O, with oil, for the purpose of lubricating the pivot and also to increase the buoyancy of the wheel. Many thousands of these styles of inferential meters are in use abroad; the manufacture of which has been developed to a high degree of excellence.

In Figs. 7 and 8 are presented two representative meters of the positive single piston type, but differing widely in detail. In the Kennedy, the piston is nearly as long as its stroke, packed by means of a ring, N, of pure gum rubber, which rolls between the piston and the cylinder, insuring an absolutely tight joint with but little friction. The register and valve mechanism is contained in a separate chamber, A, from which water is excluded. The plug valve, D, is operated by the vibrating weight, C, the weight being primarily actuated by the piston rod. The extent
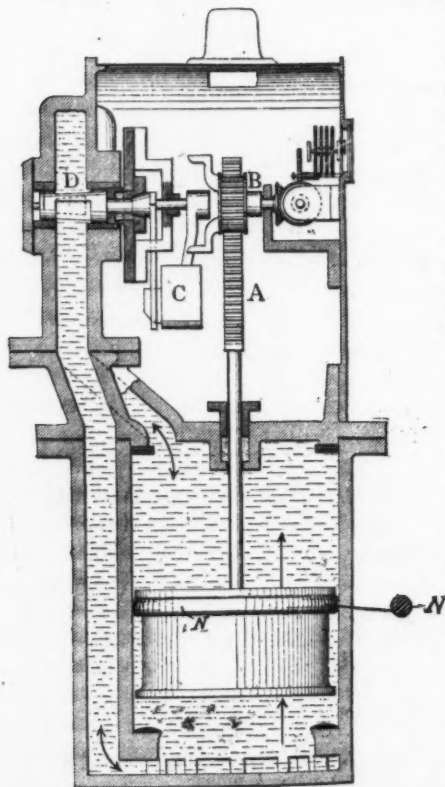
Fig. 7.

Fig. 7.—Vertical center section of Kennedy's single piston meter. Valve operated by a vibrating weight. Register mechanism records the total travel of the piston. Made in Scotland and Europe.

of the travel of the piston (not the number of its reciprocations) is
transmitted to the register by the rack and pinion, B, and a system of
ratchets and pawls.   Hence, any change in the relation of the speed
between the action of the weight by gravity and the movement of the
piston due to various rates of de-
livery, will not materially affect the
registration.   This meter has never
been introduced to any extent in this
country, but is largely used abroad;
and although it is possessed of re-
markably interesting features and is
a very accurate meter, its accuracy
seems to have been obtained at the
expense of every other desirable ele-
ment, as it is bulky, noisy and
expensive. In the Frost meter, the
main piston is packed, like a ram, with
cup-leathers, I. The auxiliary piston,
C, is also packed with leather; its
function being to operate the main
slide-valve, D. The auxiliary piston
is controlled by the primary slide-

Fig. 8.

valve, A, operated by the piston-rod, B.   The valve and register mechan-
ism are contained in the inlet water chamber, P. The register, by means
of the pawl and ratchet, records each alternate stroke of the main
piston; hence, unlike the Kennedy, if the strokes vary, for any cause,
the registration will also be at fault. This meter, under several detail
modifications, has been quite largely manufactured in Great Britain and
France and to a limited extent in the United States.
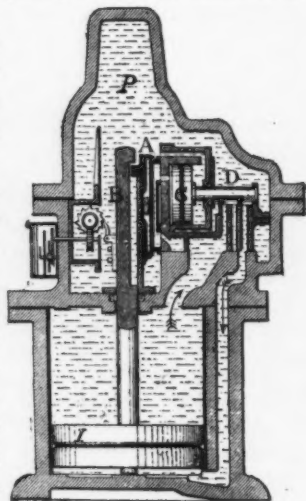
Fig. 9, Plate X, represents a meter exhibited at the Paris Exposi-
tion of 1889, manufactured in England. The writer is not aware to what
extent it has been introduced abroad. Its manufacture was undertaken,
with some detail modifications, by an American Company about two years
ago, but has recently been abandoned. The peculiarity of this device
consists in the vanes, V, which are caused to vibrate on their axis by
means of the cam, C. Hence, the operation is produced by the differ-
ence of pressure between the flat and edge surfaces of the vanes, as V^1,

Fig. 8.—Vertical section of Frost's positive single piston meter. Valve operated posi-
tively by an auxiliary piston of relatively small size. Register records the number of piston
strokes. Made in England, Europe and United States.

V^3. It appears that the same objection found against Fig. 1 would be equally applicable to this.

Figs. 10 and 11, Plate X, represent analogous devices whose generic base may be readily discerned in Fig. 1, from which the sliding and rotating wing has been expanded to the sliding and rotating piston, Z. But in consequence of the greater displacement capacity and the
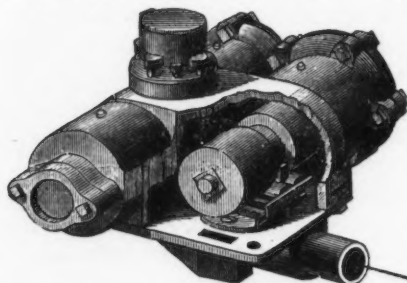
Fig. 12.

larger area of bearing surface of this device, it is not subject to the criticism made against Figs. 1 and 9. It has been quite extensively introduced in England and to a limited extent in the United States.

In Fig. 12 is presented the original type of duplex piston meter, which to all practical purposes was in fact the pioneer meter of the United States. It is still manufactured in essentially its original design and has otherwise been copied and modified. Were this instrument provided with registering mechanism embodying the principle of Kennedy's—it now records the number of piston strokes —it would present about all the most desirable features that could be tabulated in favor of this type of meter.

In Fig. 13 is shown a representative positive rotary meter, quite extensively manufactured in this country. And while it is open to the criticism quoted against Fig. 1, it is yet due to truth
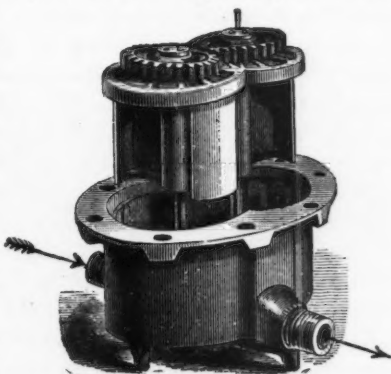
Fig. 13.

to say that careful workmanship and skillfully selected material have combined to largely overcome in practice the theoretical objections to its

Fig. 12.—Perspective exterior and interior view of Worthington's positive duplex piston meter. Made in the United States.
Fig. 13.—Perspective detail view of positive rotary meter. Made in the United States, and known as the "Union Rotary."

defective principle; as the meter in many instances has proved accurate and durable. Its origin is easily traced to the device shown in Fig. 19.

Figs. 14 and 15, Plate XI, show a positive single-piston meter similar to that of Fig. 8, except in its valve-mechanism. In this device the two pairs, K, of coupled puppet-valves were actuated by the spring-toggle, J, and vibrating lever, L. From $30 000 to $40 000 was expended upon the development of this meter before it was ascertained that it was impracticable and would have to be abandoned. There were, and there demonstratively are, a number of good and sufficient reasons therefor; but the object of this illustration is to explain one of the principal causes of its failure whereby to show how easy it is, even for meter experts occasionally, to primarily fail to observe what afterward appears to have been constantly obvious, too ridiculously simple to have escaped detection. The reciprocations of the slotted piston-rod, E, acted upon the lever, L, to cause its vibration. Now, it is to be noted that the tension of the spring-toggle is upward, acting through the lever directly upon the boss, P, to force the valves to a tight seat. When the piston-rod engages the lever, however, the tension of the spring-toggle would be transferred from the valves until the knife-edge bearing, r, was carried past its center, when the spring would act with great rapidity to reverse the valves. During the time of the described action, the valves were relieved from the pressure of the spring and were hopefully expected to be retained in proper postion by water pressure, more or less variable, acting upon the seated valves; but when a series of conditions, or "happens," so to speak, combined to work in unison, the uncontrolled valves would be unseated, and the result would either be vibrations and water rams of great rapidity and intensity, or a total stoppage of the meter.

The meter illustrated in Figs. 16 and 17, Plate XI, brings prominently to the mind of the writer the remembrance of an amount of labor, worry, vexation and disappointment which had but one compensation, that common to us all, he apprehends, the education due to a flat, uncompromising failure. And although he has never since been able to look upon these drawings without a feeling of regretful self-reproach at the utter depravity therein contained, and the inane stupidity of its author for not having more promptly discovered the default, he has yet concluded to here refer to it for the possible good of those whom it may concern. It may be said that this machine, under favorable conditions, was almost theoretically perfect in action and measurement. The diaphragm,
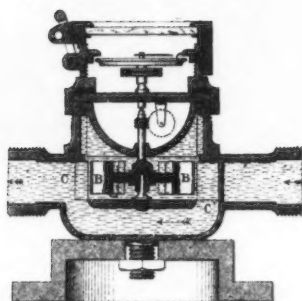
Fig. 5.

Fig. 6.
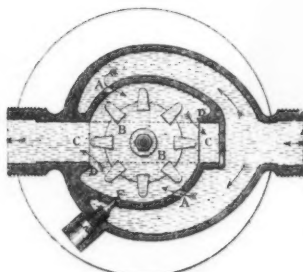
Figs. 5 and 6.

Vertical centre and horizontal
sections of Tylor's Inferential
Rotary Meter, Impact type.
Made in England.
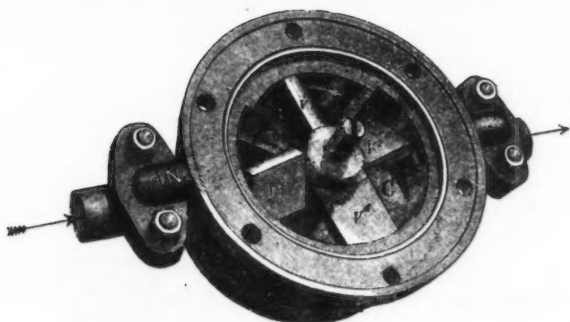
Fig. 9.

Positive Rotary Meter with Vanes
vibrating axially. Made in England
where it is designated the "Differential;"
has also been made in the U.S. as "Niagara."
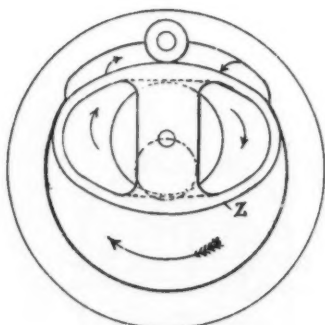
Fig. 10.

Positive Rotary Meter
with rotating and sliding
piston. Made in the U.S.
and known as the "Undine"
Patented by E.C. Terry,
April 11, 1882.
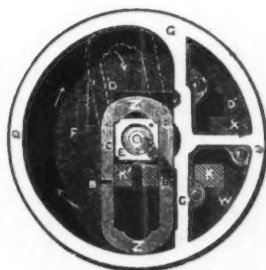
Fig. 11.

Positive Rotary Meter
with sliding and rotating
piston. Made in England
where it is known as "Kent's
Uniform."
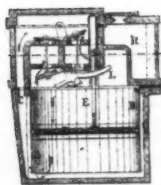
Fig. 14.

*Vertical centre section of
Positive Piston Meter with
valves actuated by springs
Its manufacture has been
abandoned.*
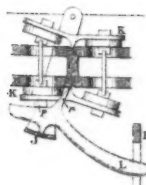
Fig. 15.

*Detail view of valve
action of Meter shown
in Fig. 14.*
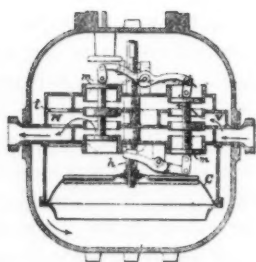
Fig. 16.
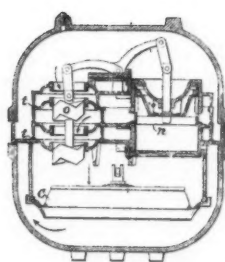
Fig. 17.

*Vertical centre sections of Positive Diaphragm
Piston Meter, with Positive valve action.
Its manufacture has been abandoned.*
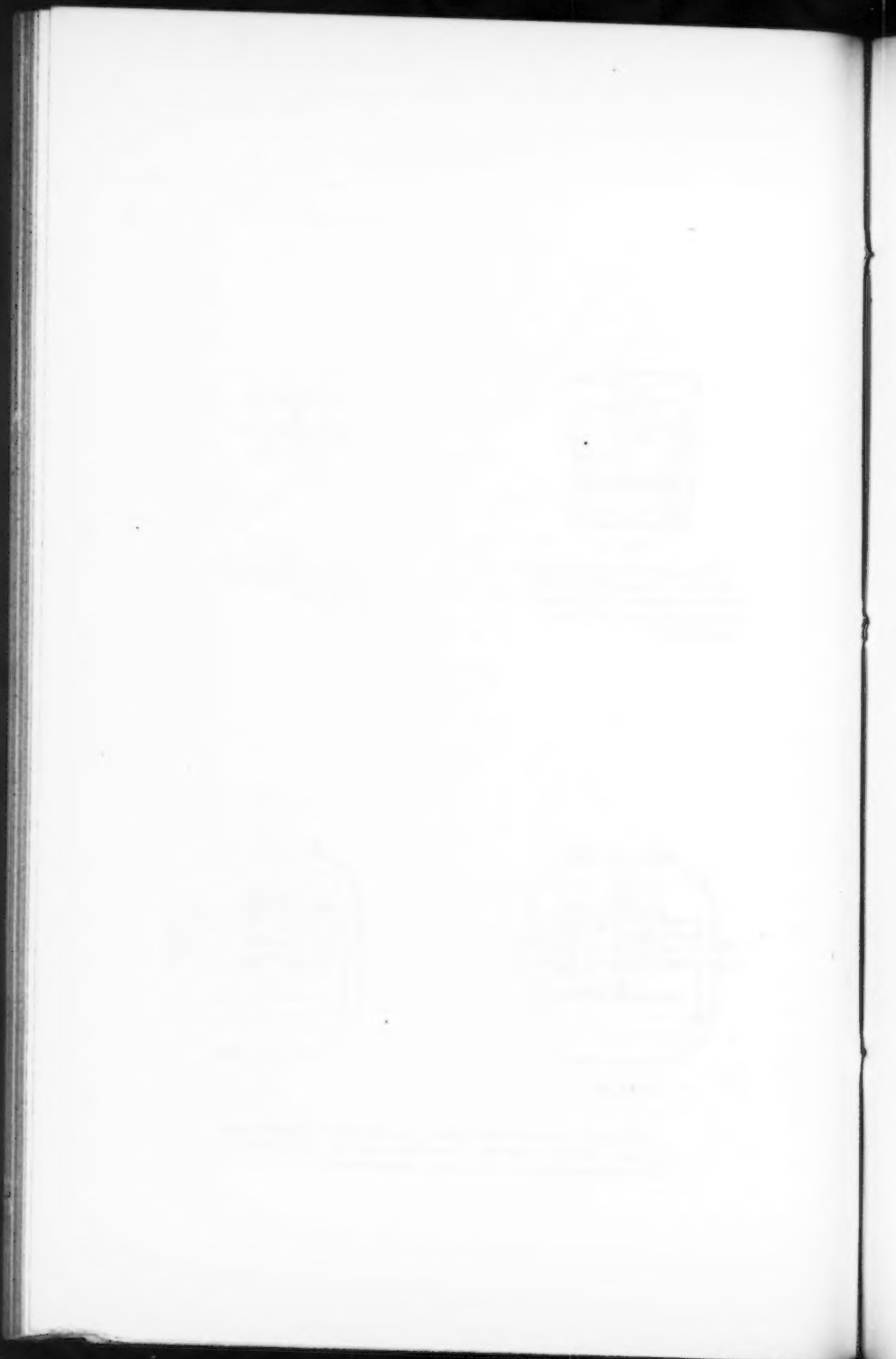
C, was of gum-rubber, usually about $\frac{1}{16}$ inch thick, but the mechanical resistance and balance of internal pressures were so nicely adjusted that a ⅝ inch meter has been experimentally operated under 30 pounds pressure, at a flow equal to 1 cubic foot a minute, with an elastic gum-rubber diaphragm no thicker than a sheet of ordinary writing paper. It was decided to employ a system of piston valves because these could be the most perfectly balanced to the impact and reactive effects of the dynamic condition. The piston-rod, h, acting upon the lever, l, reversed a pair of coupled valves, m, which controlled the supply to an auxiliary piston, n, it in turn acting to reverse the main valve, o. The conditions in the water ways, necessary to the employment of the piston-valves, were exceedingly difficult to devise; and even when these conditions had been discovered it was found that the casing could not be cast with cores, which resulted in the expedient of constructing it in separate horizontal sections and afterward soldering them together, as at t, to form a single part. This mode of forming the casing proved to be entirely satisfactory, and less expensive than ordinary cored castings. The object of forming the main valve, o, with the zigzag edge, as shown, was to gradually close and open the ports to permit rapid reversal without excessive pulsation in the pipe. The auxiliary piston also acted in a similar manner to that of the main valve, and metallic impact was avoided by means of water cushions. In these particulars the device was in fact successful, and several hundreds of these meters, under favorable conditions, performed satisfactorily; but it was found that when, say, six meters would register and otherwise perform as desired, the seventh would be troublesome or entirely fail; it would be as if possessed of an evil spirit. Inspection of the mechanism in operation through heavy plate glass, under actual working conditions, revealed nothing; the vibrations of the valves either appeared as perfectly rhythmical as the oscillations of a pendulum, or if they failed there was no evidence as to the cause. Finally, after weeks and months, a theory was evolved; the experiment to prove the theorem came readily enough; the mystery was solved and chagrin came with it; for it was immediately evident that, under the conditions required, the fault was without remedy. And this is what the author had learned: That between the inlet compartment, v, and the outlet compartment, w, at rapid rates of discharge, there was sufficient difference of pressure to cause a current of so high velocity to pass the closely but necessarily freely fitted valves, as to

carry the valves in the same direction as the current.   That was all; but
it was enough.

In Fig. 18 we have an action
first brought into prominence
by Ericsson's application of it
to marine engines.   Its next
important use, in popular con-
sideration at least, was in the
celebrated "Navarro" meter,
of which about ten thousand
of the 1-inch size were made
for New York City, and for
which the city ultimately paid
over $1 200 000.   The device

Fig. 18.

is obviously inferior to a cylindrical piston and cylinder, and has prop-
erly had but little attention from mechanicians.
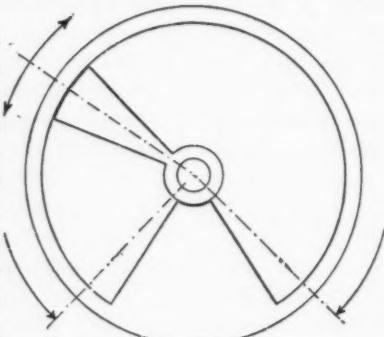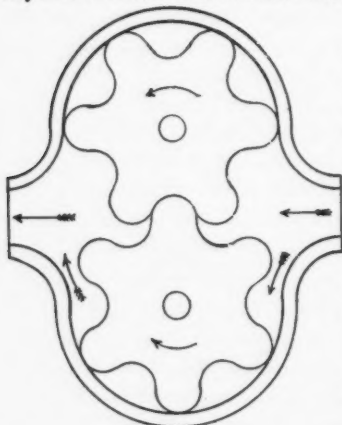
Fig. 19.

Fig. 19 represents the origin
of such meter actions as those
analogous to Fig. 13, the "Shedd,"
and many others.   This may be
regarded as the genus of this type,
for it has probably been more
closely studied, and has been the
subject of more modifications than
any other rotative movement, both
in its application to pumps and
engines as well as to meters.

Fig. 20 represents a device
which was of no practical import-
ance in the art until modified and
adapted for use as a water meter
by Nash, Gaskell, Tilden and others.   This diagram shows pistons, c, of
two, three and four wings or lobes working in a casing, d, having three,
four and five spaces.   The displacement is positive.

In Fig. 21 it is to be observed that there are here shown seven spaces,
d, and six "teeth" or lobes, e.   When a tooth is forced into a space the

Fig. 18.—Diagram of positive vibrating or wing piston movement. A very old device
used in engines, pumps and meters.
Fig. 19.—Diagram of positive rotary action. A very old device, whose generic base is
found in any pair of spur gears. It is known as "Pappenheim's" Wheels.

fluid will be displaced therefrom. The piston, c, contained in the casing, r, partakes of two movements, one of rotation, t, the other axial revolution of the spindle, i. The axial motion is differential, derived from the rotary; the relation, therefore, being as the spaces to the teeth, hence each tooth will eventually enter all the spaces. The movement is identical with that of a pair of external and internal gears, otherwise termed an annular train.

Fig. 20.
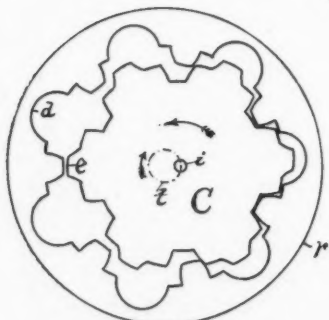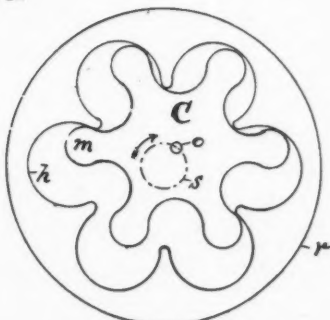
Fig. 21.   Fig. 22.

Again, in Fig. 22, it is to be noted that the number of spaces, h, and teeth or lobes, m, are here equal to each other. Each tooth or lobe "rotates" within a space, receiving and displacing therefrom. There is no axial revolution, but the spindle, o, describes a circle, s, due to the translatory movement of the piston, C; hence each tooth continually operates within the same space. Both of the devices shown in Figs. 21 and 22 have proved very satisfactory in American practice, and many thousands of meters employing these devices are now in use. It is to

Fig. 20.—Modified diagrams of Galloway's positive rotary action. Patented in Great Britain, 1846, as a steam engine. The generic base of this device is found in any pair of internal and external gears.

Fig. 21.—Diagram of positive rotary meter, devised and patented by Lewis H. Nash. Derived from the movement shown in Fig. 20. Made in the United States, and known as the "Crown."

Fig. 22.—Diagram of positive rotary meter, devised and patented by James H. Tilden. It is also derived from the movement shown in Fig. 20. Made in the United States, and known as the "Hersey."

be said that the spindles, in neither of these devices, have any impor-
tant function other than to transmit motion to the register, the thrust
of the pistons being borne by the exterior surfaces of the teeth.   At the
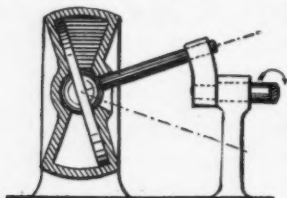
Fig. 23.

same time they are open to a like criticism
urged against Fig. 1: that is to say, small
displacement with great area of obstruc-
tion; but with this notable exception,
undoubtedly the key to their success,
namely, that the area of their bearing sur-
face is equal to that of the obstruction.

In Fig. 23 is presented the original
of the now fairly well-known "disk-action." This is really the oscillat-
ing movement of a disk controlled by a ball-and-socket joint, although
it is popularly designated as a rotary motion.   The disk-action was first
taken up in the United States about ten years ago by the Colt's Patent
Fire-Arms Manufacturing Company, of Hartford, Conn., whose Me-
chanical Engineer
at that time was
Professor Charles
B. Richards, until
recently a member
of this Society. In
the instance of the
Colt's Company,
the device was em-
ployed in a steam
engine, the func-
tion of the disk
being to transmit
the thrust of a
series of pistons,
to convert recipro-
cating into rota-
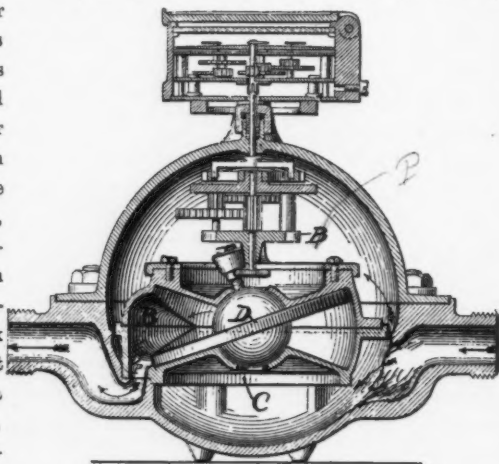
Fig. 24.

tive motion.   The writer's relation to the Colt's Company kept him, so
to speak, in touch with the development of this engine, and the very able
work expended thereon by Professor Richards, all of which resulted in

Fig. 23.—Diagram of positive oscillating movement, usually termed the "disk action."
Patented in Great Britain, first in 1830, by the Dakeynes, Davis, Bishop and Ericsson, as a
pump and engine.
Fig. 24.—Vertical center section of positive oscillating or disk meter.   Made in the United
States, and known as the "Thomson."

my being smitten with the "meter fever" and also with the controlling advantages believed to inhere in the disk-action for such a purpose. In fine, the subsequent result was the meter commercially known by my name, and here illustrated in Fig. 24. The improvements made in this application of the device referred to the internal casing, C, form of ports, B, method of controlling the movement of the disk, D, arrangement of gearing, P, etc. Unlike other actions, the displacement capacity is much greater than the obstruction. A meter employing the disk-action was made in England several years ago, but its manufacture was abandoned. The structural difficulties of this device are very great, and have probably been the chief reason why it has not received more extended attention. Several thousands of meters, made to the design here shown, have given excellent satisfaction in practice, proving remarkably accurate and durable. They are very compact and light, have a high capacity, and are noiseless in operation. At the Paris Exposition of 1889, a 1-inch meter of this design was shown in operation under a head of less than 1 inch.

To successfully work out what has well been termed the "meter problem" requires most careful consideration of and adaptation to several important conditions. On the one hand the practical and technical requirements of water-works officials, on the other hand the engineering and commercial necessities of the manufacturer. Though distinct, all are interdependent, and failure to meet one usually means failure in the whole. It is now proposed to take up very briefly these phases of the subject.

In Europe the necessity for economy in the public water service is probably accountable for the much greater use of meters which there exists than in America. It is certain, too, that the employment of meters abroad has resulted in a satisfactory reduction of the water-waste, notwithstanding the fact that this has been largely accomplished by the use of the low-priced and comparatively inaccurate types of inferential meters. Hence, there is here presented the apparent necessity for close measurement, but with satisfactorily economical results being derived from the employment of what is generally conceded to be the most inaccurate type of domestic water-measuring instruments.

With us, however, it is but a slight stretch of poetical license to say that, when the water-works engineer, who for years has stood complacently by while water has been wastefully served at from 75 to 150 gal-

lons per capita per day, who then suddenly concludes to apply a few
meters to check this lavishness, his economy goes not only to the dol-
lars but to the pennies; the meter is required to measure down to drops,
and a standard of accuracy is not infrequently set up which but few
laboratories have the means of verifying, and fewer water-works em-
ployees the ability to carry out.

The point of this is that for all practical purposes, in ordinary public
service, a meter which would register to within 5 to 7 per cent. of accu-
racy, between fair minimum and maximum rates of discharge, is, in the
writer's judgment, as in that of many others, amply accurate to effect
the desired purpose. And when our water-works officials will have
arrived at the same conclusion, meters may then be purchased at a dis-
count from present net prices of from 20 to 25 per cent. Furthermore,
such a standard of accuracy would, in ordinary practice, result in de-
creased cost of maintenance and increased life to the meter, because of
the practical conditions of service under which meters are frequently set.

These conditions, to the novice, appear somewhat severe; for it is
usually expected of a meter that it will operate with equal uniformity,
durability, and accuracy, whether the water is from a crystal spring, from
the bottom of a settling basin, or from a long dormant "dead end"
filled with gravel, scale, paint, and decayed vegetable matter. It must
be capable of standing idle for six months, while the proprietor is absent
on a European trip, and start with promptness and accuracy, to full
capacity, upon the instant of his return; it must not obstruct the flow;
it must not grind or pulsate, to the annoyance of fine-strung nerves; it
must be able to pass and measure the agile eel or the more phlegmatic
infant alligator; for the owner it must record full measure, but to meet
favor with the householder it should always register rather under than
over the actual quantity. In fine, like the great apostle, it should be all
things to all men.

One of the perplexing difficulties to be met with in meter practice is
the determination of the maximum rate of discharge for the several sizes
of meters, as this involves not only the limit of safety but of durability,
and it is clear that upon this may devolve the commercial success of the
undertaking. In casting around for a basis of computation one might
naturally turn to what is usually regarded as good engineering practice
in respect of water-pipes, but when a superintendent fits up his bench-
testing appliances under such conditions as to blow through a meter the

greatest possible quantity in the shortest possible time, the meter man finds himself in this dilemma: either he must design his meter to stand excessive duty, or he probably will not long be a maker of meters.

One of the most difficult experiences met with in practice has been to make clear to many water-works superintendents that, in selecting the size of a meter, conditions of operation have frequently much more to do with the quantity discharged than the mere matter of pressure. As bearing upon this subject, the author submits the following paragraph which he put into a trade catalogue about two years ago:

Regarding the matter of "pressure" as affecting the volume delivered, we have found a surprising extent of misapprehension, or looseness in the use of terms, in this respect, as, for instance, when it is advised that "Piston meters of rapid motion should not be used under pressure exceeding 50 pounds," etc. Such expressions have been well termed "using words without fully rendering them into thoughts," for it would seem that the merest tyro in hydraulics ought to appreciate the palpable fact that a meter may be used more destructively under certain conditions, at a head equal to, say, 15 pounds pressure to the square inch than under other conditions at 50 or 150 pounds pressure. The whole matter may be briefly explained under two simple conditions, namely: First, the greatest static pressure should be known, to the end that suitable provision therefor may be made by the manufacturer in the cylinders, flange bolts and gaskets; and, second, the greatest possible volume, or quantity, that will ever be required to pass the pipe in a given time, where it is intended to place the meter, should also be known, that the proper size may be selected. It is thus an equation of quantity into time, and these are determined by the simple element, pressure, and the complex but all-important factor, conditions of operation. The cases are most frequent in which a meter smaller than the pipe may be properly set, while in other instances—as free outlet, no "back-pressure," under-suction, large supply, or in circuit with a motor—a meter larger than the pipe may properly be required. We repeat, it is the volume of water delivered per minute or hour of time which should determine the proper size of meter to be selected, as upon this will depend the number of motions its mechanism must make in a given time. A water meter is like a steam-engine without a governor; it is but fair to expect, therefore, that they shall be set under such conditions as to preclude a rate of operation which, in the engine would be dangerous, and in the meter would be destructive of itself.

From whence it follows that probably three-fourths of the meters in public use to-day are considerably underworked; and that, if proper judgment could be depended upon in selecting the capacity of the meter

to the duty to be performed, still more compact and less expensive nominal sizes might be the result.

Although the foregoing can hardly be expected to be taken as a compliment to the efficiency of water-works employees in general, and motives of policy alone would determine omission thereof, it must yet stand, in that, first, it is well within the truth, and, second, because it is intimately related with the future of this subject; for in the writer's belief and judgment, the proximate increase of efficiency in water-meter practice will come quite as much from the better knowledge and practice of water-works employees as from direct improvements in meters by manufacturers and engineers.

But these strictures against water-works officials and employees are not to stand alone; for the author believes that more legitimate failures in meters can be directly traced to inattention in the working up of details by meter manufacturers, than to their failure to select sound principles upon which to build.   It is no salve to the vexation of a traveler who has missed a train, because his watch has stopped, to inform him that the watch failed of its duty simply because of interference between the hands. It indeed might have been more satisfactory for him to have learned that the main-spring or balance-wheel pivots were broken. And precisely so in a meter. The failure that comes from a faulty gear train; a defective screw, or an unskillfully packed stuffing box, is quite as likely to militate against the system as if the controlling principle itself were wrong. It is as well authenticated as any of the grand elementary principles, and may stand the present digression, that it is the obscure details, the little things, because unrecognized or passed by as " good enough " or as of no consequence, which most often stand as the dividing line between that which shall be successful and enduring, or unsuccessful and short-lived.

As to whether there has been, during, say, the past twenty to twenty-five years, any marked increase of accuracy in water meters, considered simply and solely on this feature, the author would answer, No. As an instance, reference may be had to the Kennedy meter, described in the Proceedings of the British Institute of Mechanical Engineers, so far back as 1856, and which yet retains its old time prestige of being one of the most accurate of water-measuring instruments. But what has been accomplished by modern workers, and to a marked degree, has been to retain a high standard of accuracy, between wide ranges of discharge,

combined with reduction of weight, bulk, first cost and cost of mainte-
nance.

Were the question asked, Has any generic invention of marked
importance been made in water meters during, say, the past twenty to
twenty-five years, the reply would promptly be made, No, there has
not; for it is a well known fact that the water meters now in the market,
both in the United States or in Europe, have either survived the period
named or are modern adaptations of, and improvements upon, old and
comparatively well-known devices.

It is to a most pronounced degree remarkable with what thorough-
ness and inclusiveness, both in detail and scope, the mechanicians of the
early part of this century took up the development of devices pertinent
to meters, pumps and engines.   This is a matter, so far as the author is
aware, that has not heretofore been specially commented upon, and it
would be an interesting comparative query to answer if any similar con-
dition exists in other branches of kinematics.   One cannot rise from an
investigation of this character without a feeling of increased admiration
and respect for the engineering ability of the period referred to, whose
bequests often form the foundation, and are even as the retaining walls,
of many modern business successes.   Thus, when Siemens took the Barker
Mill, a reaction motor of but little efficiency, and made of it a meter of
a considerable degree of accuracy; and whose economic results in the
saving of water can hardly be over-estimated, it was not a simple
transfer in name but involved close and clear mechanical reasoning.
In the positive piston meter of Kennedy, the rolling piston packing,
and the method of registering the extent of piston strokes, are funda-
mentally as perfect to-day as they were over thirty-five years ago.
The masterly conception of Worthington, who took a pair of simple
pistons and a pair of equally simple valves, and so disposed them that
one caused the operation of the other, creating the duplex type, dispens-
ing with springs and weights, has never in these features been suscept-
ible of improvement.

Now, while it is not to be overlooked that the production of the com-
pact, high-speed, rotary meters of the present day would have been im-
possible at the time when the links were being forged to form the chain
of this branch of kinematics, for the one reason, if no other, that the
necessary material was not at their hands; this but quotes an additional
obligation, to another art distinct and separate herefrom, to which the

modern engineer is in honor bound to make acknowledgment, that is to Goodyear's discovery of the vulcanization of rubber. Without hard-rubber, or "ebonite," the meters of Nash, Tilden, the writer and others would have been practically impossible of accomplishment; for no other combination of material, yet discovered, will in a meter so successfully withstand long severe service as rubber and the bronze compositions.

If of good quality for this purpose, hard rubber is of but little greater specific gravity than water, therefore presenting the minimum of inertia to be overcome; water is to it a fairly good lubricant; it is readily molded to the approximate, and even to the exact form desired, while it is also susceptible of being readily worked by ordinary machine processes; it is possessed of considerable rigidity and tensile strength; it is furthermore highly resilient, and probably to this characteristic is due, more than to all others, its remarkable efficiency in this art, and but for the fact that it is susceptible to the effect of hot water, becoming plastic therein, it would be in every particular, for this purpose, without flaw.

Notwithstanding what has been said, and while it may illy behoove one to claim originality of production for that which has been a free gift of time, modern workers need not hesitate to assert that many of the early contrived motions, although but recently adapted to meters, were made possible of success only by improvements in detail and machine processes; which, if measured upon the basis of practical results, are little if any inferior to the generic principle involved; for while it is true that Pappenheim, Galloway, Dakeyne, Ericsson and others had given us the thought, it is equally true that the seed had lain dormant until, with proper conditions of time and circumstance, they were exhumed, refashioned and transposed to a state of perfection and efficiency not dreamed of by the originators.

Reference has been made to the degree of accuracy which is regarded as sufficient in meters to be used in ordinary domestic service. This of course is simply an opinion. As a matter of fact, however, all of the principal meter makers in the United States regularly turn out meters capable of registering within probably 1 to 1.5 per cent. of accuracy, between ranges of 100 per cent. in rates of discharge, and having a guaranteed "life" of from five to ten years. For close scientific work, as in boiler testing, the writer has frequently provided meters calibrated to

practical accuracy, and that, too, with a range of 50 per cent. in rate of discharge.

The recent reductions in the cost of aluminum have made this an inviting material for experiment as a possible substitute for hard rubber, but the results so far, in the writer's experience, have been quite unsatisfactory; as it was found that aluminum when contained in ordinary brass castings with water, whether static or flowing, developed galvanic action, that resulted in producing a deposit which accumulated upon the aluminum element, to such an extent as to soon interfere with the proper mechanical operation of the parts. That this was in fact due to galvanic action was apparently proved by removing the brass element and immersing the aluminum in water contained in an ordinary porcelain basin, when no deposit took place. These experiments were tried with the regular commercial grade of metal, about 98.5 per cent. pure, made by the Pittsburgh Reduction Company, and also with aluminum made by the Castner process, claimed to be about 99.5 per cent. pure. If anything, however, the purer metal appeared to be the more readily acted upon. Mr. Alfred E. Hunt, M. Am. Soc. C. E., is now investigating the subject, and will undoubtedly soon be in a position to describe the cause thereof, even if unable to designate the remedy; neither of which is within the scope of the writer, who simply pretends to here note the results of his observations in this particular.

As to the future demand for meters, it is as certain to increase as it is certain that the water supply is more nearly a constant quantity than the consumption thereof; consequently, the trend of the purchaser on the one side is to the lowest price for equal value in performance; while on the other side the effort of the engineer is to meet the demand, which inevitably must come, under these premises, from the system involving the minimum of material and workmanship.

As to the arguments that may be made, pro and con, in respect of the different types of meters, they will of necessity partake of the color and form peculiar to the individual. Thus, a peculiarity has been observed in patent practice, common with applicants who appear for the first time in this class, in that their invention is liable to be entitled a fluid meter. It is not enough that it is a water meter of the first order; but it must include all fluids as well. However, with increased experience it is usual to find that a more specific title is accepted, even when, in patent office phraseology it is also guarded by the words "Substantially

as specified." And so as to the arguments for types of meters; if con-
fined to the conditions to be met in service the specific features of ad-
vantage or disadvantage, one way or the other, may be grouped in small
space.

In respect of the reciprocating piston meters, particularly of the
duplex type, they are reliable, fairly accurate and durable. On the
other hand, the objections to be urged are that they are bulky, heavy,
limited in maximum capacity, cause pulsation and often water-hammer
in the pipes, usually present serious obstruction to the flow, and are
expensive to manufacture. Bulk and weight are objected to because of
increased expense and trouble in shipping and setting; pulsations in
mains are annoying, particularly in house service, and are also delete-
rious to fittings; obstruction to the free discharge, where the effective
head is already barely adequate, may mean much loss of time to the
householder or to the manufacturer.

In respect of the positive rotary meters, they are also reliable, usually
very accurate and durable. About the only objections that can be urged
against them are, that when hard rubber is employed in their construc-
tion, they are liable to damage from hot water and may, to use a water-
works phrase, occasionally "go to sleep;" that is, if obstructed by sand
or scale, permit a small flow to pass without registration. On the other
hand, they are compact, light, inexpensive to transport, convenient to
handle and set, may usually be constructed of bronze composition
instead of iron, and are susceptible of manufacture at a low price.

In regard to the inferential rotary meters for small services, it is
probable that there is no future for this style of meter in the United
States, and also that their use abroad will decrease. The reason for this
opinion is that the positive rotary meters can now be sold at a price
approximating that of the inferential; and as the positive class of rotary
meter is more accurate and durable than the inferential, the controlling
advantages heretofore possessed by the latter—compactness and low
price—are neutralized.

As to the type of the meter of the future, for the smaller services, it
seems clear, therefore, that the light, compact, and low-priced positive
displacement "rotaries," whose efficiency is now well established, are
certain to supplant the more cumbersome and expensive meters of the
reciprocating piston type, as also the less accurate and durable meters
of the inferential system. Has the meter of the future yet been born

in thought or molded to form? The author does not believe that it has; but of this he feels confident, namely, that if it shall hope to successfully cope with the already practically satisfactory and accepted meters now in the field, pushed by efficient and energetic rival companies, having ample capital, it must not only be better in quality and performance but must also be capable of being manufactured and sold at a still lower price. And "there's the rub;" for while the author would not hesitate to contract, under a suitable retainer, to regularly bring out a "new" meter, say every successive sixty days for a year, which would in all cases be an accurate and reliable water-measuring machine, he would yet require the days to be changed into months if this single additional clause were inserted in the bond: "The meter to be commercially successful."

As to what should be the controlling and altogether essential features of the perfect meter—for it is yet to be fashioned, and is as far from accomplishment as a perfect engine or a flawless rod of steel—he would say that if Emerson had been a hydraulic engineer, this problem must have been in his mind when he wrote: "If the right theory shall ever be discovered, we shall know it by this token: that it shall solve all riddles." And with diffidence the author presumes to say that for this riddle he can supply the token, but the riddle is still for you to solve. The token is this: The perfect meter must be frictionless.

In conclusion, the author has but this observation to submit, which is especially, and with all good wishes, offered to the new aspirant who may come forward expecting to win fame and fortune from the successful working out of this problem; it is the matchless aphorism of Lord Bacon, and should be ever kept in mind: "If experiments are not directed by theory, they are blind; if theory is not sustained by practice, it is deceiving and uncertain." For in no other branch of engineering of which the writer has any knowledge is there required a closer matching, so to speak, of sound theory with good practice than in the development of a modern commercially successful water meter.

DISCUSSION.

E. KUICHLING, M. Am. Soc. C. E.—The subject of water meters has been presented in a most interesting manner by Mr. Thomson, and the memoir is worthy of careful consideration from all who are concerned in the management of municipal water-works. While it may be conceded that the only rational way of charging and paying for water consumed by individuals or corporations is by meter measurement, yet the present cost of these measuring devices and their maintenance is generally regarded as being altogether too large to render their extensive intro-duction expedient in our large cities. Many water-works officials would doubtless cheerfully recommend, and perhaps strongly urge, the adop-tion of meters for all classes of consumers, if they could obtain reason-ably accurate, sensitive and durable machines at somewhat lower prices than appear to prevail at the present time; and it is mainly in conse-quence of existing prices, which the public regards as too high, that all efforts to introduce a general meter system have, in the majority of cities, met with determined opposition.

The essential qualities of a water meter are accuracy, sensitiveness, and durability; and to render them more popular than at present, the quality of cheapness should also be added, or perhaps even be placed first. It is gratifying to learn from Mr. Thomson's paper that much might be accomplished in all of the other directions by manufacturers and inventors of such devices, if only some reduction could be made in the unduly high standard of accuracy which seems to be required in most localities. Under such circumstances, it is obvious that some fair limit of accuracy should be established, in order that the advantage of largely reduced initial cost and greater durability may soon be realized.

In lowering the limit of accuracy, however, the standard of sensitive-ness must not be affected, but, on the contrary, should rather be increased than diminished. Leakage of fittings and waste by small streams or driblings flowing constantly, usually give rise to greater consumptions than the legitimate use. The writer has often measured the leakage from a defective faucet, ball-cock, and closet-valve, in households and places of business, and found that a discharge of from 150 to 400 gallons per day from a single fixture rarely excites notice on the part of the inmates, and that a request to repair such fixture is regarded as grievous oppression. A loss of several hundred gallons per day by continuous leakage, in a household where the legitimate use is actually much smaller than this amount, is a circumstance of frequent occurrence where an efficient system of house to house inspection is not enforced. In the case of a town where the total daily per capita supply is only 50 or 60 gallons, it is obvious that all such insidious sapping of the distributing pipes will seriously impair the efficiency of the works, and perhaps even lead to a water famine.

The remedy usually prescribed in such a community is general metering; but here we are at once confronted with the fact that many of the meters in the market either fail to register such small streams, or else that the power required to overcome the friction of closely-fitted parts is greater than is tolerable. Thus, in testing recently a certain meter, which was to be set in a small private dwelling containing a family of only five persons, it was found that the machine would pass leakage at the rate of 1 500 gallons per day without registration, while on the other hand, when the discharge was increased to a rate of 5 000 gallons and more per day, the dial record was practically correct. Manifestly, such a meter is perfectly useless as a waste-preventing device, since it not only permits a leakage of at least five times the legitimate water consumption of the entire family to pass absolutely unrecorded; but it also enables any shrewd consumer to obtain vastly more than a copious supply without equitable charge, by simply allowing a small stream to flow continuously into a suitable distributing cistern. If it be assumed that a daily per capita consumption of 40 gallons is a reasonable quantity, then an average family of five persons should use 200 gallons per day, all of which would ordinarily be drawn at a rapid rate from the fixtures, and would therefore probably be recorded by almost any meter; but if only a single fixture in the dwelling were leaking at the rate of 200 gallons per day, how many meters would reveal the fact on their dials, especially after having been in service for a few years ?

It is very justly said that water is not sold to consumers by the drop or driblet, but by the gallon or the cubic foot, as the smallest practicable unit. To this statement no one should take much exception, but it is also fair to take it literally. Let the meter be sensitive enough to record, even with wide margin of accurancy, the fact that hundreds of gallons pass through it in the course of a day, and it will be a far more useful instrument to the community purchasing it than one which will exhibit marvellous accuracy in the measurement of comparatively large streams, and yet allow small flows to escape without detection. The percentage of error in registration of a meter is therefore a matter which should be sharply defined, and should be made dependent upon its sensitiveness. A loss of 10 per cent. on the above-named legitimate use of an average family would amount to only 20 gallons per day; and a loss of 25 per cent. on a leakage of 200 gallons per day is only 50 gallons, so that a total loss of 70 gallons, in this case, would be only about 17 per cent. of the whole quantity passing through the meter; whereas if the legitimate use alone were recorded with absolute accuracy, while the small leakage escaped registration, the loss would be 50 per cent. of the whole draught. In the case of meters intended for family use, which in a general meter system would vastly outnumber all other kinds, it is, therefore, essential to make sensitiveness a paramount feature, as well as durability and cheapness. The same requirements may also be made

for meters, for the majority of manufactories and places of business in a community; and in the comparatively few instances where the draught is constantly large, special meters which give a high degree of accuracy can easily be applied.

In conclusion, therefore, it may be stated that a thoroughly service-able meter should have great sensitiveness, but need not have a very high degree of accuracy. How these qualities can be combined with durability and economy is a question whose solution is left to the skill of inventors.

JOHN THOMSON, M. Am. Soc. C. E.—In reply to Mr. Kuichling: First.—I disagree with his conclusion that "existing prices" for water meters have had much to do with the matter of their general applica-tion; but with the express proviso hereto that this opinion refers to municipalities and not to private water companies. Many instances might be cited in which the application of a few thousands of meters, even at the highest prices that have ever obtained in this market, would have resulted in the saving of millions of money expended in duplicat-ing conduits and pumping plants, and in paying for the wanton waste of the many. I presume to submit that if 50 000 water meters had been offered to the City of New York at, say, $5 each, with a guarantee of their satisfactory performance, under bond, for a term of ten years, that the new aqueduct would have been built just the same, although the original supply, by such means properly conserved, would in all likeli-hood have been ample for such a term. The fault with the commercial reasoning of my friend Kuichling is that he is focusing his argument with the eye of an engineer alone, with no allowance for errors of paral-lax and the aberrations due to atmospheric disturbances. Nevertheless, the fact is not to be lost sight of that very considerable reductions in the prices of meters have been made within the past few years, the cause of which, in my opinion, is not due so much to the demand for lower prices as to the increased necessity for more meters. This has been a forced exigency; it is not that their use was right, proper and equitable, but that if not employed the use of water in such instance would be greater than the supply. In any market, as well as in that of the meter market, this might properly be designated a case of forced demand, originating with the consumer. Now, with this has concurrently grown a greater incentive to manufacture, which, in turn, has engendered in-creased competition, resulted in improved designs, caused the produc-tion of larger quantities, thereby reducing the cost of manufacture; and I believe that to these exterior causes, added to those previously herein set forth, are chiefly due the present prices of our commercial water meters. And if this is true of the past, it will probably be equally applicable to the future.

But I am glad to drop this phase of the subject and take up its alter-nate side. As to lowering the standard of accuracy, this is a suggestion

which I made with considerable hesitancy, as it might be taken as appearing to advocate a step backward. Nevertheless, I am of the opinion that, in at least the great majority of instances in which meters would be comparatively largely employed, the fact of whether or no they indicated at comparatively low rates of flow would bear but a very small relation to the total advantage and revenue derived therefrom. The point made by Mr. Kuichling to permit a lowering of the standard of accuracy, while yet retaining the element of sensitiveness to such a degree as to at least indicate a portion of the entire quantity at the lowest practicable rates of discharge, is somewhat in line with the results obtained in the use of the low-priced inferential meters, a type but little known in this country. This is a condition of operation, however, which would probably be very difficult to obtain, if at all, in the existing types of positive displacement meters; although the condition opposite to this could, I apprehend, more readily be reached; that is, to cause the meter to indicate in excess of the proper quantity at the lower rates of discharge. With many private water companies, this would be desirable; but whether or no it would be generally acceptable is a question I am not prepared to answer. The argument in favor of such a condition is that when it is known the meter will over-indicate on "driblets," then a leak, ordinarily passed as of no consequence, would have the first attention. On the other hand, the proposition is freqently held that the moral effect of placing a meter in the circuit of the service pipe is in itself all that is necessary to obtain the desired result, and that if only a meter casing, provided with a register but having no internal mechanism whatever, were generally applied in cities having the highest per capita rate of consumption, this, in itself, would bring the rate down to reasonable dimensions. In such a predicament, the mean value of the extremes may be the wiser to adopt. However, it is my judgment, based upon some little personal contact with water-works engineers and superintendents, that it is very unlikely any lowering of the present standard of accuracy would be accepted; while it is equally likely that the necessity therefor will grow less and less as the administration of water-works practice improves.

With probable interest and benefit, the mechanical difficulties might now be indicated which lie in the way of putting into practical effect Mr. Kuichling's idea of partial indication at low rates of delivery; but I fear such might not be clearly presented without the employment of additional illustration, which present opportunity makes it impossible to prepare. So, too, in respect of my suggestion to reverse the condition proposed by Mr. Kuichling, whereby to obtain over-registration at low rates of flow; as a discussion thereof would, at least, trend towards the class of proportional water meters, purposely omitted from the main body of this paper, and which I have had in mind to treat separately at some future time.

TRANSACTIONS.

EXCESSIVE RAIN-FALLS CONSIDERED WITH ESPECIAL REFERENCE TO THEIR OCCUR- RENCE IN POPULOUS DISTRICTS.

By CAPTAIN R. L. HOXIE, M. Am. Soc. C. E.

READ JULY 2D, 1886.

WITH DISCUSSION.

PART I.

In the practice of hydraulic engineers it is necessary, at times, to provide absolute protection against the most violent storms that can occur in a drainage area, whether of a large or small extent ; it is of primary importance to know what such a storm is.

PRECIPITATION OF RAIN.—Meteorological records are ordinarily made from observations taken at stated intervals, rarely less than four hours, and the detailed phenomena of storms are seldom recorded. The rate of precipitation given is the mean rate of this interval, and the maximum rate has been little regarded. The importance of this maximum rate increases as the area of drainage diminishes, since a heavy rate of short duration may seriously affect a small area. The following table has been com-

All values are in inches (ins.).

Locality and Sources of Information	Duration of Rain-fall in Minutes										Duration of Rain-fall in Hours																
	1	5	8	15	20	22	25	30	40	45	1	1.25	1.50	2.00	2.33	2.50	3.00	3.25	4.00	5.00	7.50	14	24	30	36	48	56
Great Britain .... (I.)	0.2	0.75									3.25			3.50			4.00										
Washington, D.C. ......(II.)		0.52	0.47	1.0	0.73			1.8	2.0	2.5		1.25															7.92
Nottingham, Eng. ....(III.)			0.75			0.97		1.14	2.0	1.14								4.92 (a)									
Birmingham, Eng. ....(III.)							0.78	1.16																			
New York ....(III.)								1.94												4.00							
Providence ....(III.)				0.90	1.42						3.15																
London and vicinity ...(IV.)				0.50				2.00			4.00		6.00		3.30												
Paris ....(IV.)					1.61			1.26	0.64		1.57																
Switzerland ....(IV.)																	6.38										
Geneva ....(IV.)																											
Munich ....(IV.)								2.00																			
Catskill ....(IV.)		0.87									2.55																
Budapest ....(IV.)							1.57																				
Marseilles ....(IV.)																						13.0					
Genf ....(IV.)															6.39												
Kiel ....(IV.)			1.46																								
New London ....(V.)					0.93														5.00							12.0	
Norwich..............(V.)																			5.00							12.0	
Goffstown............(VI.)																									12.35		
Canton, Conn. ....(VI.)														4.00			4.27										
Concord, N.H. ....(VI.)																3.00											
Fitchburg, Mass. .....(VI.)														2.5													
Norway, Maine........(VI.)																											
Middletown ....(VI.)														6.00													
Philadelphia ....(VII.)																							7.15				
Norristown, Pa ....(VII.)																				9.00				8.90			
Genoa ....(VII.)																							32.				
Brooklyn ....(VIII.)						2.6			1.2		1.65																

piled from the sources indicated.   With a single exception it is a chance
record by occasional memoranda injected into systems of observation
which ignored the importance of this record ; as a consequence it covers
a wide field in the search for information.   The universality of the
phenomena suggests the operation of some law of recurrence which can-
not be deduced from the meagre record.

SOURCES OF PRECEDING TABLE.

(I.) From " Practical Hydraulics, a series of Rules and Tables for the
use of Engineers," etc., by Thomas Box, London, 1876.   Mr. Box says:
"For town drainage and other purposes we require to know the maximum
fall of rain during storms.   We find that * * * the maximum fall
of rain may be (as in table)."

(II.) From the meteorological records of the Signal Service, of the
Smithsonian Institute, and of the United States Naval Observatory,
Washington, D. C., including the continuous record by pencil curve of
one self-registering rain-gauge at the Signal Office, Washington, D. C.,
from 1871 to 1885, both inclusive.

(a.) A letter from Professor Joseph Henry to Major G. K. Warren,
Corps of Engineers, U. S. A., now on file in the Engineer Department,
gives the record of a storm on the 29th of July, 1865, at Washington,
D. C., in which 4.92 inches of rain fell between 3.15 P.M. and 6.30 P.M.
The rain-fall during the storm was at an average rate of 1.510 inches per
hour for three hours and a quarter; what the down-pours were can only
be conjectured.

(III.) From report on sewerage in the City of Providence, by J. Her-
bert Shedd.   The meteorological record kept by President Alex. Cas-
well, D.D., LL.D., from 1832 to 1873, in Providence, R. I., is carefully
tabulated, so as to present valuable information; but the record of down-
pours is limited to eight memoranda of Dr. Caswell, beginning in 1862.
The rate in the case of each storm is obtained by dividing the total pre-
cipitation by the whole time of rain-fall, giving the mean rate for the en-
tire period, and where the time of rain-fall was less than an hour it is
reckoned as having been an hour in falling.   This process eliminates all
down-pours and greatly reduces the recorded number of violent storms
having phenomenal rates of fall.   However, these down-pours usually
occur during the progress of storms giving a large total precipitation,
and some idea of the frequency of down-pours may be derived from the

number of such storms. It appears from Dr. Caswell's record that during the forty-two years from 1832 to 1873, both inclusive, rain-falls exceeding 4 inches occurred at average intervals of 4.62 years, the longest interval being eight years, and the shortest less than one year, while rain-falls of 2 to 4 inches occurred every year but one (1846); the least number of such storms in one year being 1, the greatest number 7, and the average 3½. Mr. Shedd quotes from the annual report of 1847 of Mr. John Roe, surveyor of Holburn and Finsbury sewers, and author of the well-known "Roe's tables." "In August last the surveyor had occasion to report that 4 inches depth of rain had fallen in less than one hour in that month, a circumstance that cannot be too extensively known at a time when much sewer work is likely to be executed in this country; for having once experienced such a fall of rain it is right to expect and provide for the like occurrence in future."

(IV.) From report of Mr. Rudolph Hering to the National Board of Health, Washington, D. C., 1881, including Mr. Hering's citation of other authorities. This, with other and valuable information, was collected by Mr. Hering in the course of an extended tour abroad for this purpose. He says: "In only two towns (Zurich and Munich) did I observe rain-gauges of this nature (self-registering), and these had only recently been placed."

(V.) From a treatise on water supply engineering, by J. T. Fanning, New York, 1878. Mr. Fanning says in this connection: "When studies of local rain-falls are confined to mean results, neglecting the occasional wide departures from the influence of the general controlling atmospheric laws, the actions of nature seem precise and regular in their successions, and in fact we find that the governing forces hold results with a firm bearing close upon their appointed line. But occasionally they break out from their accustomed course as with a convulsive leap, and a storm rages as though the windows of heaven had burst, and floods sweep down the water courses, almost irresistible in their fury. If hydraulic constructions are not built as firm as the everlasting hills, their ruins will on such occasions be borne along on the flood toward the ocean."

(VI.) From a paper read before the American Society of Civil Engineers, at their Tenth Annual Convention, June 18th, 1878, by J. B. Francis, Past President, Am. Soc. C. E. Mr. Francis writes : "In the construction of catch-water reservoirs, mill-dams, culverts in railway and

other embankments, and many other works, provision has to be made for the maximum flow of water. In small areas this depends, to a great extent, on the maximum rain-fall in a given time." With the painstaking thoroughness of the "Lowell experiments," Mr. Francis has collected from a great number of observers the details of a rain-fall of about thirty hours' duration, and claiming only "a rough approximation" shows that the precipitation of—

Square Miles.

6 inches or more covered an area of				....	24 431
7 "	"	"	"	....	9 602
8 "	"	"	"	....	1 824
9 "	"	"	"	....	1 046
10 "	"	"	"	....	519
11 "	to 12.35 "	"		....	179

The isohyetal lines surrounding the central area of maximum precipitation with the symmetrical curves of the barometric wave. The observer at Concord, N. H., reports: "4 inches of rain fell between 12.30 P.M. and 2.30 P.M., October 4th." The observer at Goffstown, N. H., reports: "4.27 inches of rain fell between 11 A.M. and 2 P.M., October 4th." The observer at Fitchburg reports: "about 3 inches of rain fell between 11.30 A.M. and 2 P.M., October 4th." The air line distance from Concord to Fitchburg is about 45 miles, with Goffstown nearly on the line between them; if this distance be taken as the diameter of the area of simultaneous down-pour, it covered about 1 590 square miles.

(VII.) Trautwine. This author says : "The most destructive rains are usually those which fall upon snow, under which the ground is frozen so as not to absorb water."

(VIII.) From a report on the sewers of Brooklyn, N. Y., by Robert Van Buren and William E. Worthen (1878).

MAXIMUM FLOOD-FLOW.—In general, at any point in the course of the outflowing water, it will be found that the maximum flood flow from the drainage area under consideration is the most dangerous consequence of excessive storms, while the length of time such maximum flow continues will have more or less effect in augmenting the danger, or in extending its field of menace. When one of these great reservoirs of aqueous vapor opens its flood-gates by condensation and pours down its maximum rate of fall, it saturates absorbent surfaces if not already saturated, ponds upon flat surfaces to gather surface slope for discharge to the nearest channel, and then every point in the drainage area which the

precipitation covers becomes a fountain of drops, one following another in quick succession, and a fillet of drops proceeds from every point at once. They meet in rills and rivulets; they gather in the smaller streams, and flow in company to join with others in the larger branches. At any point in the course of the outflowing water, the fillet from the nearest point of the water-shed appears at once and continues to flow, while others join it in quick succession from points more and more remote, until the fillets from the rim of the water-shed, gathered in the tributary branches, are flowing together past the same point of the main channel. This is the maximum effect of the down-pour, when the grasp of the main channel encircles, at once, a fillet of drops from every point in the area it drains. The effect is quickly developed in the smaller streams, and moves down the main channel as fast and as far as the fillet of drops from the point most remote or that which is most belated by obstructions to flow, can travel while the down-pour continues. When the rain-fall slackens, the fillets dwindle, and when it ceases, the fillets entering the channel in front of the flood-wave run out to the end, one by one, through the channel, in advance of the coming wave, and fail to re-inforce it. The first effect, the conditions of which are simple, is the danger to be averted in the smaller drainage areas; the after effect, in which the crest of the flood-wave follows the slackening or cessation of rain-fall, is the dangerous effect in the larger basins, and is more complicated.

The maximum flood-flow from any drainage area is a function of many variables; the total precipitation of rain producing the flood; the mean rate of precipitation, the fluctuations in this rate giving periods of maxima and minima with their respective intensity and duration; the proportion of the drainage area covered by the precipitation, its location with respect to the point under consideration, its shape and topographical features, its general slope and distribution of hillside and valley with their relative slopes; its capacity for pondage in lakes, ponds and storm channels, and the character of its surface as affecting the question of absorption and evaporation over the entire area under varying meteorological conditions during the critical period between the commencement of the rain-fall and the arrival of the flood; as well as the friction in channels and other sources of detention of flow from the surface. In large river basins it is not practicable to ascertain the actual conditions of the problem; in smaller areas the difficulty diminishes until, in urban

districts of roofs and pavements only, these conditions may all be ascertained. As the natural surface changes by human agency, the rate of maximum flood-flow increases; trees and shrubs disappear and the surface flow is accelerated. Cultivated lands with tile drains and ditches further increase the rate of flow. When a drainage area lies within city limits, all pondage is obliterated; a surface more or less absorbent and retentive is replaced by smooth and non-absorbent roofs and pavements; eave-spouts, gutters and drains of quick discharge take the place of filled-up natural channels.

MAXIMUM FLOOD-FLOW IN CITY DRAINS.—If a typical city area be assumed completely covered with roofs and pavements and provided with a completed system of drains, into which all the rain-water finds its way from roof or pavement at once, the drains having sufficient capacity to carry the maximum flood-flow, this question is greatly simplified. The falling water finds a smooth channel from the start which conducts it by the shortest line to the outfall. Modern hydraulic formulas give with close accuracy the conditions of flow in these channels. The meteorological records of the locality should indicate the storms which have occurred, and which may therefore occur again; absorption by surfaces of metal and stone, and evaporation into a saturated atmosphere during the period of maximum rain-fall, may be accurately computed. It has been shown that 94½ per cent. of a brisk rain-fall upon such a surface may be collected and discharged through a system of drains,* which was manifestly imperfect, while a natural surface of 6.6 square miles has delivered 98 per cent. under favorable conditions. The great work of main drainage of London brought prominently into notice the question of conveyance of rain-fall in city drains, the subject being incidentally investigated at that time by the eminent engineers connected with this project. In the plans adopted, this investigation has little weight. The several lines of intercepting sewers constructed to convey the sewage of the metropolis to a distant outfall, receive the dry-weather flow of the old valley sewers with a fixed and insignificant amount of rain, and pass the storm-flow through by overflows to be carried forward to the "Thames" in its former channels. In this way the question of storm-flow in the new works was practically eliminated; but the investigation evolved some interesting information, nothing more prominently than the prevailing ignorance of the

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* June, 1885. The Iron gate sewer. Mr. W. Haywood in a discussion before the Institute of Civil Engineers, London, 1865.

probable storm-flow in city drains. In fact, the existing sewers of London were generally of insufficient capacity. Mr. Jebb in his "report on the drainage of the metropolis," 1854, says that many of the sewers were "unnecessarily large, still more of them too small, the consequence of which latter defect was that tenements were flooded and property destroyed to a great extent annually." Roe's tables, published in 1852, and Mr. Hawksley's formula, which gives quite similar results, became prominent, and were generally accepted as standard authority; they have continued in use to the present date.

ROE's TABLE, showing the quantity of covered surface, from which circular sewers, with junctions properly connected, will convey away the water coming from a fall of rain of 1 inch in the hour, with house drainage, as ascertained in the Holburn and Finsbury Divisions.

INCLINATION FALL OR SLOPE OF SEWER.	INNER DIAMETER, OR BORE OF SEWER IN FEET.									
	2	2½	3	4	5	6	7	8	9	10
	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.
Level......................	39	67	120	277	570	1 020	1 725	2 850	4 125	5 825
¼-in. in 10-ft. or 1 in 480	43	75	135	308	630	1 117	1 925	3 025	4 425	6 250
½ " " " " " 240	50	87	155	355	735	1 318	2 225	3 500	5 100	7 175
¾ " " " " " 160	63	113	203	460	950	1 692	2 875	4 500	6 575	9 250
1 " " " " " 120	78	143	257	590	1 200	2 180	3 700	5 825	7 850	11 050
1½ " " " " " 80	90	165	295	670	1 385	2 486	4 225	6 625		
2 " " " " " 60	115	182	318	730	1 500	2 675	4 550	7 125		

Level sewers have a capacity which diminishes with their length, the friction head being continuously formed at the expense of depth of flow in the sewer. In this respect the table is evidently unreliable. The sewers with stated slopes must be proportioned to take the maximum flood-flow in each case, else they would not suffice. Applying to the table, Kutter's formula, for the flow of water in circular conduits, we get the actual capacities of these sewers and find that they indicate a maximum rate of flood-flow (9 cubic feet per second), only 2-10 the mean rate of precipitation (1 inch per hour), for the smallest area (43 acres) of city surface, and a maximum rate of flood-flow (1 317 cubic feet per second), only 12-100 of the mean rate of precipitation for an area of 11 050 acres; yet modern observation has shown that from a small natural water-shed with natural channels, under certain conditions, the

maximum rate of volume of flow through the outlet channel may reach
two-thirds of the average rate of volume of rain falling upon the gathering
ground.* The storage reservoir of the Nagpoor Water Works, of British
India, receives the drainage of 6.6 square miles of natural surface. On
September 16th, 1872, there occurred a fall of 2.2 inches of rain in
eighty minutes, a rate of 1.65 inches per hour. In one hundred and
seventy minutes 98 per cent. of the total rain-fall was gathered into the
reservoir, the ground being saturated when the storm occurred.† Nearly
the same quantity (2 inches), has fallen in half the time (40 minutes),
and a mean rate of 1.51 inches of rain-fall per hour has been sustained
three hours and a quarter in the District of Columbia.

If such facts be considered with the conditions of city surfaces and
swift flow in city drains, it will be seen why Mr. Roe's table and Mr.
Hawksley's formula, have uniformly failed to give sufficient capacity to
drains which must actually take the rain-fall. Plotting separately the
curves of capacity for the several inclinations given in Mr. Roe's table,
it is found that for equal areas the capacity required for an inclination
of 1 in 60 greatly exceeds that for an inclination of 1 in 480, the differ-
ence increasing steadily to about 40 per cent. for an area of 6 250 acres.
If these slopes be indicative of the general slope of water-sheds, as in
valley sewers, this increase would harmonize with the more rapid dis-
charge from steeper slopes; but the slope of 1 in 120 requires, by the
table, a less capacity than either of the slopes of 1 in 160 or 1 in 240, and
the capacity required for the two latter is nearly the same for equal areas.
It is probable that Mr. Roe's twenty years' observations are vitiated by
the same source of error that prevails at present. A natural surface
gathers all the flow of rain-fall into its natural channels, but nearly all
systems of town drains are imperfect as collectors of storm water. In a
slow, gentle rain, the inlets may receive it all; in sudden down-pours
they are unable to take it in; they are often proportioned to reject it,
and a variable quantity escapes over the surface. This erratic variable
discredits all gaugings of storm flow in sewers, and accounts for the ex-
traordinary variations shown.

Mr. W. Haywood says, in 1865 : "Of a rainstorm of 0.54 of an inch in
five hours, in June, 1858, there was delivered into the Iron-gate sewer,
which drained an area entirely paved and built over, as much as 94½ per
cent. of the total rain-fall, and that, of all the storm gaugings he had

* Fanning.
† A. R. Binnie, M. I. C. E. Proc., Inst. C. E., Vol. 39, 1874-75.

made, was the greatest percentage of rain-fall he ever knew to be dis-
charged by a sewer. In August, 1858, with a rain-fall of 0.48 inch in one
and two-thirds of an hour, he found only 78 per cent. of the total
quantity discharged in the Iron-gate sewer." It will be noted that in a
moderate rain of 0.54 of an inch in five hours, 94½ per cent. found access
to the drains, but in a violent rain of 0.48 of an inch in one and two-
third hours, only 78 per cent. got in. Absorption and evaporation had the
better chance to deplete this volume in the first case. Had the sewer
drained a basin without surface outlet the ratio of loss in the second case
would, doubtless, have been less than in the first. When such gaugings
pertain to sewers having a fixed regimen, *i. e.*, into which no larger pro-
portion of flood-water will ever be permitted to enter, they give useful
information for that sewer and for no other. Unfortunately the deduc-
tions from the record of these sewers have been promiscuously applied
to others—even to sewers and drains which, draining basins without sur-
face outlet, were compelled to carry off the total rainfall. It will be
noted that the distinguished engineers connected with the London main
drainage works did not go elsewhere for statistics, but gauged the actual
flow of the old sewers which they had to deal with.

The published records of sewer gaugings are in other respects un-
satisfactory. While they show that urban surfaces are practically im-
pervious, and evaporation insignificant in violent storms, the rate and
duration of the maximum flood-flow has received but little attention.
Instead of this, the time in which a certain proportion of the rain-fall
passes off, is used to deduce a mean rate of flow.

In Mr. Shedd's report on the sewerage of Providence, two diagrams
are published from a report of Mr. Roe, in 1852 ; these show, conspicu-
ously, the time of appearance, volume, and duration of the maximum
flood-flow in two cases—incidentally, however, as they are intended to
"illustrate the length of time required for the water of a rain-fall to reach
the sewers." In a rain-fall of ½ inch in three hours the maximum effect
was developed in three and three-quarter hours, but the effect of the
storm continued for twelve hours. In a rain-fall of 1.11 inches in one
hour, followed by 0.33 in the next two hours, the maximum effect was
developed in about three-quarters of an hour, before the first heavy fall
had slackened, but the storm water continued to flow for sixteen hours.
The maximum flood-wave developed in the second instance was the
dangerous maximum resulting from a simultaneous flow from all points

of the drainage area during the maximum rate of precipitation. It would
be interesting to know how far from the head of the system it traveled
before the slackening of this rate occurred. Of these diagrams, Mr.
Shedd says: "Unfortunately Mr. Roe does not give the rate of inclina-
tion nor the character of the surface from which the water flowed, nor
other facts which it would be useful to know; but I infer that the dia-
grams are given as fair samples of what may be expected in a district like
this, where the extreme difference of elevation is about 400 feet in a dis-
tance of 5 miles."

No 1.

No 2.
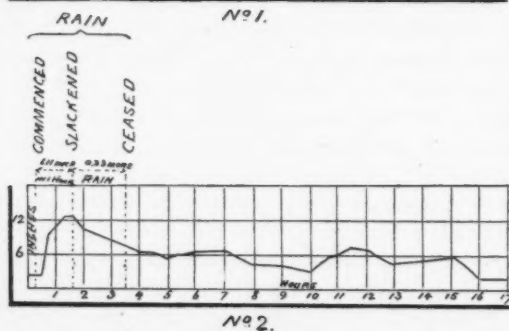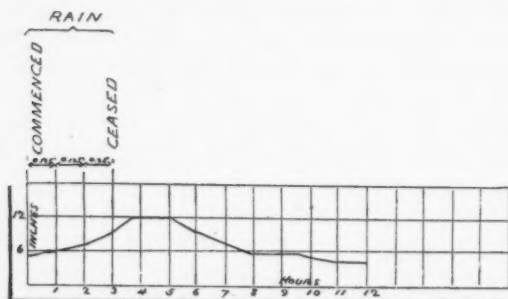
An average velocity of 6 feet per second in a completed system of
drains would carry the maximum flood-wave due to a down-pour of one
hour's duration to a distance of 21 600 feet from the most remote point
of the rim of the drainage basin. If the main drain lie symmetrically in
the valley of its drainage area, and the latter be semicircular—a shape
to which the upper portion of such areas frequently approximates, this
distance of 21 600 feet, say 4 miles, is the radius of a semicircular area

of 50 square miles, from every point of which the maximum flood-wave 4 miles from the rim at the expiration of the hour, would be drawing a contribution. Long after the down-pour was over, the mean flow would be passing the outlet, and long after that the miles of gorged drains would continue slowly to empty themselves.

Of the rain-fall of October, 1869, which he investigated so thoroughly, Mr. Francis writes : "At Concord, N. H., out of the whole rain-fall of 7.40 inches, 4 inches fell in two hours on the afternoon of the second day of the storm, and undoubtedly in many other localities there was a like down-pour, and in some places even more. This inequality in the rate has an important bearing on the effect of such a storm on small areas. The long-continued and heavy rain must have filled up the ground and usual storage reservoirs, and, being followed immediately by a fall of rain which, of itself, would make a flood, a great part of the latter in a hilly country must have passed at once into the streams, and the flow in the smaller streams, for some period of time, must have been nearly that due to the rate at which the rain was falling on the water-shed supplying them."

On June 28th, 1881, a rain-fall of 2.68 inches occurred in Washington, D. C. It included a precipitation of 1.78 inches in twenty-five minutes, a rate of 4.23 inches per hour. The New York Avenue intercepting sewer had just been completed. It drains an area of 436 acres, of which 200 acres are paved with asphalt and closely built over ; 80 acres are open park, and 156 acres are sparsely built upon but mainly paved with asphalt. The inlets for storm water were imperfect, and in heavy showers a large quantity of water flowed over the surface of the streets across the line of the intercepting sewer. Under these circumstances the sewer was gorged, the water rising high above the crown of the arch in the manholes. It was computed by Kutter's formula to carry 2 inches of rain-fall per hour, or about 2 cubic feet per acre per second. In this instance the rain preceding the down-pour had saturated what little absorbent surface existed, and the down-pour itself must have been thrown off with hardly appreciable loss. Allowing five minutes to develop the maximum surface flow toward the drains, twenty minutes of down-pour remained, during which a mean velocity of 5 feet per second would carry the maximum flood-wave from the most remote point of the crest of the water-shed to the outlet. The mean velocity in these drains is probably about 7 feet per second, and there

can be little doubt that had the main sewer possessed the requisite
capacity and suitable inlets, its flow must have been for some period
of time nearly that due to the rate at which the rain was falling on its
water-shed of 436 acres.

In 1884, a self-recording gauge was placed at a point in this sewer
where it is circular in section, 8 feet in diameter, and carries the drain-
age of about 200 acres paved with asphalt and well built up. After the
gauge was placed in position a storm occurred of $\frac{1}{2}$ an inch in fifteen
minutes, a rate of 2 inches per hour. The flow in the sewer rose
almost immediately after the rain began, and fell to its normal level
within a few minutes after the rain ceased; its maximum height was
$5\frac{7}{10}$ feet, or about three-quarters the capacity of the sewer. A second
storm occurred June 28th, 1885. The record of the sewer-gauge tallied
exactly with the rain-gauge of a few minutes earlier. At its maximum
period the rain fell for thirty-seven minutes at the rate of 0.9 of an inch
per hour. The sewer-gauge rose to a height of 3.7 feet, giving about
0.47 of the capacity of the sewer, and indicating no loss whatever by
absorption or evaporation during the time of maximum flow.* The
rain-gauge in each instance was that of the Signal Office, situated within
this water-shed near its western border, but outside of the 200-acre
paved area to the eastward. If the distance from the rain-gauge to the
crest of the water-shed on which the maximum effect was gauged, be
taken as the radius of the area covered by these storms, this area was
about 4.7 square miles. The storm of June 28th, 1881, showed the
effect of violent precipitation over at least 10 square miles. Not
unfrequently a statement of excessive storm-flow from such a water-
shed is met by a comparison with the summer flow of rivers, upon
the assumption that the disproportion in areas discredits the observed
fact. If it be remembered that the flood-flow of some navigable rivers
is from 200 to 1 500 times their least flow, the comparison has no sig-
nificance.

THEORETICAL CONSIDERATION.—Notwithstanding the complicated
nature of this question, the absence of sufficient data, and the imper-
fection of records, a great number of formulas have been devised to
solve the problem. The comparison of these is instructive.

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* Reports of Commissioners, D. C., for 1881-84.

TABLE of maximum flood-flow in cubic feet per second from drainage areas of 64 acres to 6 square miles, computed by various formulas.

Square Miles of Area Drained.	DISCHARGE IN CUBIC FEET PER SECOND.												
	Craig.	Dredge.	Dick-ens.	Fan-ning.	Kirkwood.			Hawksley.			Burkli Zeigler.		
.1	282	222	147	29	18	21	22	17	35	41	61	135	161
.2	469	353	247	52	35	40	41	30	63	73	103	228	271
.3	625	462	334	73	51	58	60	42	87	102	139	309	367
.4	763	560	415	93	65	75	78	53	110	129	173	383	455
.5	889	650	491	112	79	93	96	64	132	155	205	453	538
.6	1 007	734	562	131	93	108	112	74	153	179	234	519	617
.7	1 116	813	631	148	107	124	129	84	174	203	263	583	693
.8	1 221	889	698	166	120	142	145	93	194	228	291	644	766
.9	1 321	962	762	183	133	157	162	102	213	250	318	704	837
.10	1 416	1 032	825	200	147	172	178	112	232	272	344	762	906
.20	2 225	1 638	1 388	356	273	323	333	195	408	476	579	1 281	1 523
.30	2 886	2 146	1 881	500	390	464	479	269	565	662	784	1 736	2 064
.40	3 463	2 600	2 334	635	503	597	623	340	711	837	973	2 153	2 561
.50	3 9~6	3 017	2 759	765	613	734	787	405	850	997	1 150	2 546	3 028
.60	4 468	3 407	3 163	890	720	863	891	468	985	1 158	1 319	2 919	3 471

NOTE.—Where more than one variable enters the formula, the values assumed are indicated in the description following, and are taken so as to give such uniformity of conditions as the formulas will admit. The three columns given to each of the last three formulas correspond to slopes of $\frac{1}{480}$, $\frac{1}{20}$ and $\frac{1}{10}$ successively.

Mr. Craig's formula is the following:

$$D = 440 \times B \times N \text{ hyp. log. } \frac{8 L^2}{B}.$$

In which D represents the discharge in cubic feet per second; L the extreme length, and B the mean breadth of the drainage area, and N an arbitrary constant varying from 0.37 to 1.95, which depends upon the meteorological and topographical conditions of the locality; the least value of N is assigned to very flat river basins. In applying the formula to river basins, the flood discharges of which have been observed, and from which the values of the arbitrary constant are deduced, the author gives no example of an area less than 120 square miles, but the mathematical deduction of the formula applies equally to the smallest area. The meteorological conditions considered being those which apply to large river basins in India, the principal factor is the mean intensity of prolonged rain-falls there. The greatest value of the mean intensity of a prolonged rain-fall in India may be fairly compared with the mean intensity of the down-pours in this climate, which are of shorter duration, and are destructive in comparatively small areas.

In the table $L = \sqrt{\dfrac{5\,M}{4}}$, $B = \sqrt{\dfrac{M}{5}}$, M = area in square miles, and $N = 1.16$. The Dredge formula resembles Mr. Craig's in introducing the shape of water-shed:

$$Q = 1\,300\,\frac{M}{L^{\frac{2}{3}}}.$$

In which L is the length of water-shed, and M the area in square miles. In the table $L = \sqrt{2\,M}$.

Colonel Dickens' formula is the well-known type of formulas, having but a single variable, the area:

$$D = 825\,M^{\frac{3}{4}}.$$

In which D represents the discharge in cubic feet per second, and M the area of drainage basin in square miles. Mr. Fanning's formula is of this type. In presenting it, the author says the recorded flood measurements of American streams are few in number, but upon plotting such data as is obtained, we find their mean curve to follow very closely that of the equation:

$$Q = 200\,(M)^{\frac{5}{6}}.$$

In which M is the area of water-shed in square miles, and Q the volume of discharge in cubic feet per second from the whole area. All of the foregoing apply to the natural surfaces of river basins.

In the Burkli Zeigler formula:

$$Q = R\,C\,\sqrt[4]{\frac{S}{A}}.$$

The arbitrary constant C represents the character of surface, the highest value 0.75 being for paved streets and densely built up areas, the lowest value 0.31 for macadamized streets; R is the average intensity of rain during the period of the heaviest fall in cubic feet per acre per second (for Central Europe this rate was found to be from $1\frac{3}{4}$ to $2\frac{3}{4}$ cubic feet per acre per second), S is the general grade of area per thousand, Q is the water reaching sewers in cubic feet per acre per second.[*]

In this formula Q increases with R, C and S, and diminishes as A increases. The condition of equal delivery per acre from all areas, large or small, is that $S = A$. The formula takes no account of the shape of water-shed.

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[*] Report of Mr. Rudolph Hering to National Board of Health, June 28th, 1881.

In the table $R = 3$ cubic feet, $C = 0.75$ and $S = 2.08$, 50.16, and 100, successively.

Mr. Kirkwood's formula is:

$$D = \left(\frac{N^2}{5804S}\right)^a$$

in which D is the diameter of sewer in feet; S the sine of inclination, and N the number of acres of city area which this sewer will drain. In the deduction of his formula Mr. Kirkwood assumes a maximum rain-fall of 1 inch per hour, and a maximum outflow of one-half of this for all areas, large or small. He uses Prony's formula to deduce an expression for D, which he then modifies so as to make the results conform to Roe's tables. Q is obtained in the above table by using Kutter's formula, with values of D and S obtained from Kirkwood's formula, and $S = \frac{1}{480}$, $\frac{1}{20}$ and $\frac{1}{10}$ successively.

Mr. Hawksley's formula is:

$$\log. D = \frac{3 \log. A + \log. N + 6.8}{10}$$

in which D is the diameter of sewer in inches, required to carry off the outflow from 1 inch of rain per hour; A the number of acres to be drained, and N the length in feet in which the sewer falls one foot. Both the formula and the tables are designed exclusively for city or suburban surfaces. Values of Q in the table are deduced by using Kutter's formula with values of D and N obtained from Hawksley's formula, and $N = 480$, 20 and 10 successively.

The formulas of Kirkwood and Hawksley, and Roe's tables, are functions of two variables only, the area of drainage and slope of conduit; each is independent of slope and other characteristics of water-shed, except as this slope may conform to that of the conduit, as in valley sewers; and all rest upon the assumption of a maximum rain-fall of 1 inch per hour. It will be observed that they give values of maximum flood flow for paved areas, which are far less than the actual observed flood flow for natural surfaces. The conclusion is inevitable, either that the maximum rain-fall assumed is very much too small, or that the formulas resting upon sewer gaugings extending over a period of twenty years, represent the flow of rain-fall that found access to the sewers, and not the maximum flow that will obtain under circumstances which require them to take it all. It seems probable that they are affected by both sources of error. These formulas and tables have been

extensively used in designing sewers and drains, with the uniform result
of disaster whenever the drains have been actually required to perform
the service for which the formulas and tables declare them competent.*

Applied to the gauging of New York avenue sewer, in Washington,
D. C., in 1884 (see *ante*), empirical formulas give the following discord-
ant results:

CAPACITY in cubic feet per second required in a circular sewer, draining
200 acres of paved surface, to carry off the rain-fall. The slope of
the sewer being .002 and the general slope of water-shed being .008:

RAIN-FALL.	ROE'S TABLES.	HAWKS-LEY.	KIRK-WOOD.	BURKLI ZIEGLER.	ACTUAL MAX. FLOW AS GAUGED.
.5 inches in 15 minutes	36.3	43.2	51.7	137.6	300
.55 inches in 37 "	36.3	43.2	51.7	61.9	180

In the first case the maximum rate of outflow, as gauged, was three-
fourths the rate of downpour (2.0 inches per hour). In the second
case the maximum rate of outflow, as gauged, equaled the rate of down-
pour (0.9 inches per hour). Either the duration—fifteen minutes—
was not quite sufficient to develop the maximum effect of the first
storm at the point where the gauging occurred, or its violence caused
the escape of a small proportion over the surface. It will be noted that
the formula of Burkli Ziegler gives for this water-shed a maximum rate
of outflow 33½ per cent. of the maximum rate of any rain-fall, while the
gauging in the second instance shows no difference in these rates. If
the maximum rate of rain-fall be assumed at 2 inches per hour, the
formula gives a capacity of main drain about one-third the capacity of
the existing drain which has been gorged in actual service.

Professor J. B. Johnson has recently been arguing with much force
the sheer impossibility of expressing by means of formulas the condi-
tions of flow of a river at any point, comparing the problem with that
of the determination of the instantaneous relation existing between the
pressure of the piston of a crank-engine, the resistance to motion, and

* The formulas of Kirkwood and Hawksley apply to a fall of only 1 inch in one hour, and
deem this sufficient provision for storms; but Mr. Roe has another table for 2 inches of rain-
fall per hour, and has recommended that provision be made for a storm of 4 inches in one
hour.

the velocity of the flywheel.* It requires no argument to point out the impracticability of such generalizations as are involved in empirical formulas for maximum flood flow. They are useful, as each suggests its relation to the cases to which it is made to conform, and so widens the field explored; but there is no legerdemain in hydraulics which can solve a problem of twenty independent variables by the use of one or two. These empirical formulas "which can only be applied with confidence within the limits of the experiments on which they are based," are too often mistaken for devices by which a few hours of elementary computation may suffice instead of laborious thought and thoroughness of investigation.

PART II.

EXPEDIENCY OF MAKING ADEQUATE PROVISION IN SYSTEMS OF DRAINAGE FOR EXCESSIVE STORMS.

The necessity for such provision is well recognized in all hydraulic works, the destruction of which by flood would involve loss of life or serious damage to property. The primary object of the earliest sewers was such provision for storms. When their use as sewers developed the fact that their shape made them unsuitable for this purpose, "the separate system" of small sewers arose and has ever since taunted the "combined system" with its former size. The old storm sewers of great size and with flat inverts were certainly not adapted to the conveyance of sewage; but given sufficient capacity, their original sin, and every one of them might have been provided with an invert as in the Paris main sewers, which would carry the dry weather flow to the best possible advantage and with absolute precision of adjustment to its fluctuations, while the storm capacity remained intact. The expediency of so doing is another question. Mr. Rawlinson, the apostle of the separate system, had a profound respect for the magnitude of the task imposed upon the combined system by the duty of conveying storm water. In his "Suggestions," he says:

"Hydraulic tables may be of service, but they must be applied under the discrimination of practical knowledge, or they may prove to be more misleading than useful. For main sewering the engineer may profitably consult tables of rain-fall, or areas, and of the flow of water from the site, and it will be quite in order for him to do so; but if he

* Proceedings of the American Association for the Advancement of Science, 1885.

attempts to apportion sewers so as to be of capacity to receive and remove the flood water 6 to 10, or more, feet below the surface, he will commit a serious and costly blunder, as heavy falls of rain cannot be dealt with in such manner. A rule-of-three sum, made up of 'area, rain-fall and dimension of sewers,' cannot safely be acted upon. Heavy falls of rain must pass at and over the surface as during previous times, or special drains must be used if they exist, or must be provided for if they do not exist; and the sewers must be confined in subsectional capacity, so as to be equal to the removal of waste water from houses and manufactures. In large towns there may be exceptions; and then, as in London, flood water overflow channels into natural streams may have to be formed."

In this he concurs with Mr. Bazalgette, who, in disclaiming any intention to take the water of excessive storms into the intercepting sewers of his London main drainage system, says, of a rain-fall of 2.64 inches in nineteen hours, " to intercept such a volume as resulted from this rain would have necessitated sewers of the capacity of rivers." Each of these engineers had a great problem to solve, from which the task of controlling storm water must be eliminated. Mr. Bazalgette passed it through his intercepting sewers, which carried all of the sewage of the metropolis, by overflows, into the old va'ley lines of sewers. Mr. Rawlinson, having for his object the rapid extension of sewerage facilities to the numerous village cities of Great Britain, the cost being the paramount consideration, advocated the minimum outlay for the smallest possible sewers, and advises carrying off flood water "over the surface," and by "existing road drains and drains to natural streams in valley lines," such as were generally to be found in these localities.

Mr. J. Bailey Denton, having in view the ultimate disposal of sewage, writes:

"To ascertain the amount of surface water to be admitted into sewers, or to be discharged by separate surface drains, it is necessary to have regard to the rain-fall of the district, and the maximum downfalls to which it is subject."

     *   *   *   *   *   *   *

"It is in fact with considerable difficulty that the engineer arrives at the amount of surface water for which he must provide, in one way or another, by admission into the sewers, or by discharge through surface drains."

Mr. Baldwin Latham, the advocate of the combined system, and perhaps the highest authority upon this subject, says of deep sewer drains for the common conveyance of rain-water and sewage:

"Having ascertained the amount of rain falling in the district to be dealt with, which, for the purpose of being practically useful, should show the maximum quantity of rain that falls in the shortest time, all sewerage works must be calculated to convey away, either by the sewers

or by storm-water overflows, or special works constructed for the purpose, the maximum amount of rain without flooding or inconvenience to the inhabitants of the district."

This opinion would apply with equal force to the so-called clean-water sewers, which have been proposed to take the rain-fall in the separate system. The question cannot affect the relative cost of the two systems. Given the same duty to carry storm water, and the same capacity of conduit for this purpose is required in either case. The difference in cost will be always that due to the difference in depth of excavation; and against this the combined system, with its single deep sewer-drain, urges the whole cost of the additional small sewer required by the separate system. The engineers quoted are recognized leaders of the profession in this specialty; they agree in recognizing the difficulty of dealing with excessive storms, and while prescribing different methods of making provision for them, it occurs to neither of them to advise that such storms be left to take care of themselves because of their infrequency.

In 1878, the Common Council of Brooklyn resolved that "Whereas the matter of constructing storm sewers is a subject of very great importance to several localities of the city, which sadly need relief from the effects of sudden falls of rain" * * * "competent consulting engineers" should be selected, "and a full report be made by said engineers at an early day, giving their opinion as to the best and most economical plan for permanent relief."

These engineers reported as follows: "Your engineer has for several years been aware of the importance of improving the sewerage system, and the frequent complaints of householders in certain localities of the city have caused the most careful investigation to be made from time to time. The flooding of basements and cellars depreciates the value of property and endangers the lives of those occupying the flooded dwellings. * * * We find an unfortunate basin. * * * We find streets a mile or more from the water front graded about 8 feet above high-water level, and entire districts but a little over 10 feet above high tide. * * * We are convinced that many of the main sewers have become too small since the districts have been built over, and are, in many instances fixed at too low a grade. The lower portions of many districts are frequently inundated. * * * Grades have been established which make pockets or basins, and all the rain-fall not absorbed or evaporated must be discharged through the sewers."

They note the actual rain-fall of the locality, including precipitations of 1.65 inches in one hour, 1.2 inches in 40 minutes, and 2.6 inches in 25 minutes, and remarking that "In this view, and with the knowledge obtained from rain records, we have thought best to discard entirely English formula and try something applicable to our situation and locality; they recommend the construction of a number of relieving sewers, of large capacity at a cost of $750 000."

PRACTICAL CONSIDERATIONS.—When a drainage basin which includes a large city extends far beyond the probable extension of the latter; the

stream flowing through the city will ordinarily have a natural channel, which will command respectful consideration in time of flood. It is generally the lesser streams of smaller basins lying mainly within the limits of the present and prospective city that become the objects of empirical formulas for replacing the natural channels with artificial drains. In large cities and their suburbs, over which the conditions of a dense population will sooner or later extend, the question of disposal of storm water is not affected by the present condition of such suburb; the engineer must provide for the future. In all cities rain falling upon the surface of the streets and open spaces finds entrance to the drains only by street inlets, and may be excluded from them; falling upon roofs above the level of the streets it may be turned upon the streets; falling upon back yards, or upon areas below the street grade it must enter the drains unless surface drainage be provided by alleys in the rear. The proportion of rain-fall which may flow upon the streets will consequently vary from the whole amount to perhaps 60 per cent., the latter including only rain falling upon streets and roofs. It follows that 40 per cent. of the rain-fall is ordinarily the greatest proportion that must flow directly to the drains. The 60 per cent. falling or turned upon the streets may be left there, or any desired proportion may be turned into the drains by the street inlets. Whether it be advisable to make use of the street surface as a channel for storm water—for all, or for any part of it—will depend upon the local conditions; but, ordinarily, the inconvenience of conveying storm water upon the surface constrains all large cities to desire its conveyance under ground. Street surfaces are poor substitutes for natural channels.

It will often happen that long valleys of slight inclination, and even large basins without surface outlets, compel the underground conveyance, under penalty of inundation. Frequently the surfaces of streets covering a large tract of land are placed so far above the general elevation that to fill up the lots to street grades for surface drainage would cost very much more than would the additional capacity of main drains required to take from such areas the total outflow of excessive storms. It will sometimes happen that a system of storm drains which has proved too small may be relieved by conveying excessive storm water over streets to relieving or intercepting drains; and at all times existing works for the conveyance of storm water may be turned to the best possible advantage.

The use of the main sewers as subways for water and gas pipes and other municipal service, as in Paris, requires ordinarily a capacity so great that the question of capacity for rain-fall is eliminated, leaving only the necessity for adapting the shape of the invert to the dry weather flow. In the same city the conditions will vary in different drainage areas, or sub-areas, but there are only two general cases in which provision must be made for excessive storms; one, in which the drains may be relieved of some proportion of flood water by carrying it off upon the surface; and the other, in which the drains, including existing works, must carry it all. If storm water should gorge the main drains, their backwater will flood cellars and basements connected with them. Automatic or positive action flood-valves will give a precarious protection in certain cases of back flow from the main drain, but fail too often, and prevent all outflow while they operate to exclude the flood. The cost of such a valve is ordinarily many times the cost of giving the additional capacity required for excessive storms to that portion of the main drain in front of the premises, and is imposed upon the sufferer alone. The value of protection from such flooding with foul water can only be estimated by those who have experienced such flooding, and have noted the depreciation of their property which has resulted from this risk imposed upon it. It is doubtless preferable in such cases to avoid any openings from the premises into its house drain below the hydraulic grade line of the gorged sewer, but where the basements are occupied as kitchens, etc., or the premises depend upon the drain for the removal of ground water, this is not practicable.

OBJECT OF DRAINAGE WORKS.—Drainage works have in every case a specific duty to perform—the conveyance of the maximum flood-flow from the proportion of rain-fall assigned to them, "without flooding or inconvenience to the inhabitants of the district." This duty is equally imperative, whether circumstances permit the exclusion of a large proportion of rain-fall from the drains or compel them to take it all. If the surface flow upon the streets passes off to a proper outlet without causing damage or inconvenience, the flood is well disposed of. If not, there is danger in permitting storm water to accumulate upon streets with steep grades. It becomes a torrent flowing with great velocity, and cannot then be captured by inlets designed to arrest, each, its share of shallow gutter flow with small velocity. It moves rapidly down to valleys, or basins without surface outlet; here it floods the surface because inlets

to receive it as fast as it comes can rarely be constructed—even should the drains here be of sufficient capacity. Inlets for large volumes of water in city streets are apt to be pitfalls for pedestrians and traps for cart wheels and horses' feet. If the drains of the inundated district are of insufficient capacity the consequences are, of course, disastrous. When an intercepting drain is designed to relieve such a district a definite work is assigned to it—the carrying off of all flood water falling upon the district above it, and there should be no danger of failure. Any intercepting drain should be of unquestionable capacity, because adjoining it are the smallest mains of the next sub-area, and a down-pour taxing the intercepting drain to its full capacity would rarely respect the boundry of the area, but would tax equally these small mains of the lower system. In this condition they are not fitted to receive any rejected surplus from the intercepting drain, which would flow to them over the surface. When drains are designed for basins without surface outlet, or to relieve such basins, they must of course, carry all flood water from the area which drains to them. Whether the drains must carry all, or part of the outflow from excessive storms, and whatever may be the area covered by down-pours or their duration, each sub-area of a size to be affected by it must have suitable provision in the capacity of its drains for such excessive down-pour. This compels the greatest capacity for all of the lesser mains and their lateral branches, which correspond to the upper sub-area in each drainage area, and together constitute a great part of a system of drainage. The debatable ground is, therefore, the principal main drain, and in deciding upon this in the presence of conflicting opinions as to what is required, the element of cost is too often decisive. It is proposed to show the actual relative insignificance of comparative cost.

Every main drain is like a bridge that carries over a stream the concentrated travel of many roads, a necessity to which all this travel pays toll. When a drainage area extends beyond city limits and beyond their probable extension, the cost of works which benefit only city property should not be imposed upon land in that area which will not share the benefit; but within these limits the cost of a main drain is properly chargeable to each beneficiary in proportion to the service rendered. Each square foot of area drained by it imposes an equal duty; derives an equal benefit. The cost should be equally distributed upon each square foot of area contributing its waters to the drain. This principle

has been generally recognized, but it has sometimes happened that the cost of a main drain has been otherwise provided for. When the general taxes of a city are applied to this purpose, outlying drainage areas do not get their drains until long after their proprietors have commenced to contribute towards the cost of constructing drains in other areas. If all taxpayers eventually receive the same consideration, this may be looked upon as a small loan without interest while the lenders are waiting, but the distribution of cost is not the same as in the drainage area tax for this reason: general taxes are assessed in proportion to value of property, both real and personal, areas entering only as one factor. The result of paying the cost of drains from general taxes is that the beneficiaries pay in proportion to their means, and not in proportion to the service rendered. In general it will happen that those who pay the greater portion in this way are the first to derive substantial benefit, owning the most valuable lands and being the first to feel the need of the drain; and this may be held to offset the greater burden imposed.

The special assessment plan imposes a certain proportion of the cost upon property abutting on the line of drain, upon the theory of immediate benefit. This need not prevent the equal ultimate distribution of cost. When an intercepting drain accomplishes the diversion of upland water from low grounds which cannot receive it without injury, the benefit of the drain extends far beyond the drainage area which it serves; but if the benefit be merely incidental to the service of its own area, it is, perhaps, doubtful whether any proportion of the cost should attach to the benefit on the low grounds. Within the limits of city areas and their probable extension, the cost divided by the drainage area, or the cost per square foot of drainage area, is the unit of value of service rendered. Whenever it is not necessary to modify the rule, each beneficiary will pay in proportion to the area of his land. From the record of about ten years sewer building in Washington, D. C., tables of cost, etc., have been prepared. (See Appendix.) From these the following statement has been deduced, assuming the area to be drained by a 12-inch pipe as the unit of area, and the cost per lineal foot of 12-inch pipe as unity. It is an approximate generalization.

RELATIVE COST AND CAPACITY of main drains required for various areas (without regard to slope or other characteristic of water-shed, assuming only uniformity of such conditions in the areas compared).

Col. 1.	Col. 2.	Col. 3.	Col. 4.	Col. 5.	Col. 6.	Col. 1.	Col. 2.	Col. 3.	Col. 4.	Col. 5.	Col. 6.
1	1.000	1.00000	.39200	.60800	$0.01303	80	5.210	.06500	.03784	.02716	$0.00058
2	1.174	.58700	.28100	.30600	.00656	90	5.500	.06100	.03531	.02569	.00055
3	1.388	.46200	.23160	.23040	.00494	100	5.730	.05730	.03325	.02405	.00052
4	1.567	.39200	.18190	.21010	.00450	200	8.640	.04320	.02407	.01913	.00041
5	1.743	.34800	.15800	.19000	.00407	300	11.730	.03910	.02088	.01822	.00039
6	1.920	.32000	.13700	.18300	.00392	400	13.300	.03325	.01917	.01408	.00030
7	2.090	.29900	.12180	.17720	.00380	500	14.790	.02958	.01815	.01143	.00024
8	2.250	.28100	.11090	.17010	.00365	600	16.280	.02713	.01746	.00967	.00021
9	2.410	.26800	.10530	.16270	.00349	700	17.770	.02539	.01697	.00842	.00018
10	2.570	.25700	.10000	.15700	.00336	800	19.260	.02407	.01583	.00824	.00018
20	3.170	.15800	.06500	.09300	.00199	900	20.750	.02305	.01411	.00894	.00019
30	3.480	.11600	.05040	.06560	.00141	1 000	22.240	.02224	.01274	.00950	.00020
40	4.030	.10000	.04330	.05670	.00122	2 000	36.300	.01815			
50	4.170	.08300	.04320	.03980	.00085	3 000	50.340	.01678			
60	4.610	.07700	.04190	.03510	.00075	4 000	50.970	.01274			
70	4.910	.07000	.03992	.03008	.00064						

NOTE.—For the purpose of comparison the diminution of proportional outflow with increase of area is neglected in the table, the increase of capacity required being assumed directly proportional to the increase of area. This is incorrect, but serves the purpose of making such comparison more unfavorable to the increase of capacity, and obviates the necessity for assuming any doubtful formulas.

COLUMN 1. Units of capacity or units of area drained, the unit being the capacity of a 12-inch pipe for conveying water, or the area which it will drain.

COLUMN 2. Relative cost per lineal foot of main drain for this area, the cost for the unit of area being assumed as unity.

COLUMN 3. Relative cost per lineal foot per unit of area drained.

COLUMN 4. Relative cost of a quadruple capacity per lineal foot per unit of area drained.

COLUMN 5. Excess of cost of a quadruple capacity per lineal foot per unit of area drained.

COLUMN 6. Assuming the unit of area at 6 acres, the unit of cost at $1 40 per lineal foot, and the average area of the ordinary city lot, including its proportion of street surface, at 4 000 square feet, the excess of cost to each lot in the drainage area, for quadrupling the capacity of its principal main drain, will be per lineal foot of drain, as shown in this column.

It will be seen that there is a great discrepancy between the increase of cost and the increase of capacity, nearly four thousand times the capacity being obtained with fifty-one times the cost; and that the excess of cost per unit of area drained to obtain a quadruple capacity diminishes rapidly as the capacity of the drain increases. Since the question of cost will arise upon the large main drains, the expediency of adequate provision for excessive storms in the smaller mains and laterals being admitted,

the decision to be made is, where shall the limit be placed? to what area
shall we give this insurance against excessive storms ? Being in doubt,
the fact presents itself that the higher we place the limit, the easier rests
the burden of insurance upon all whose lands, being themselves secure,
send down the dangerous floods to the point in doubt. It it be in ques-
tion to give this insurance to premises where the abutting drain conveys
the water from 500 units of area or 3 000 acres, the pessimist who has
been flooded by a gorged sewer may point out to the optimist who has
not, that the cost to those already insured of extending a like protection
to others cannot exceed one-fourth of 1 mill per lineal foot of drain for
each average city lot. It is true that the sufferers from a gorged drain
are only those whose property abuts upon the line of it, and beginning
with the small branches at the summit, if all are made of a sufficient capa-
city down to some large main drain, those above the influence of the back
water of the latter are apt to say, "After us the deluge ;" but this is not
equity. The same considerations which grant immunity to property
bordering upon the lesser mains must apply with equal force to prop-
erty lower down, otherwise the system of mains will not render equal
service to all. The cost of this insurance, or the price of a factor of
safety, is most equitably chargeable *pro rata* against those whose drains
send down the flood with safety to themselves. Considerations of tem-
porary expediency, which are always on hand to emasculate every project,
should not be permitted to influence the proper expenditure. A factor
of safety is an indispensable element of all engineering structures. It
has been called the "factor of ignorance," because it makes allowance
for what the engineer does not know. If the factor were proportional to
the extent of this ignorance it would be very large in all hydraulic con-
structions, including sewers and drains.

APPLICATION TO WASHINGTON, D. C.—While the writer has no theory
to advance, no advice to give and no formula to offer, it is thought that
the application made of the foregoing to the District of Columbia may
be of interest to the profession. In 1871 the District of Columbia was
first organized by Congress upon a basis admitting of a comprehensive
plan of public work. From this dates the inception of plans for sewer-
age, the combined system being adopted. In 1874, a change in the form
of government found the work well advanced, and many miles of brick
and pipe sewers laid, ranging from 12 inches to 30 feet in diameter or
span. The new administration, after four months' service, made their

first annual report, approving, generally, the work of their predecessors.
The sewer system had been planned in harmony with views, which were
then quite generally entertained, as to capacity required for the convey-
ance of storm-water.   During the following year the new administration
learned its own mistake and that of its predecessors; and being con-
vinced alike with the property owners whose premises were flooded, that
excessive storms should be provided for in a system of sewers, in their
report for 1875 they predicted the destruction of the largest main sewer in
Washington because of its insufficient capacity, and urged the construc-
tion of relieving sewers.   Relief was attempted by reducing the size of
the connecting pipe from the street inlets, and so excluding from the
drains nearly all storm water which flowed upon the street surface. This
sent down the floods to deluge the low-grounds, and was of little use at
the higher elevations because of the large proportion of rain-fall enter-
ing the drains from roofs and back-yards, and from surfaces below grade.
In 1876–77, the peremptory curtailment of expenditures by act of Con-
gress put a stop to all attempts at relief, but in the report for 1876 the
warning is renewed.   In 1878, 500 feet of the principal main sewer of
Washington was destroyed by flood-water, as predicted, and the com-
plaints of sufferers from back-water of gorged sewers were universal.
The new form of government of the District of Columbia was made per-
manent, and the attention of Congress having been secured, plans were
presented for the present system of relieving sewers upon which work
was commenced in 1879.

TOPOGRAPHY.—The topog. .phical sketch, Plate XII, gives the estab-
lished grades within the city limits, and the natural surface outside these
limits, covering all territory draining through the City of Washington.
There are three principal depressions within the city, shown by the
shaded surface on the map.   One of these, an elliptical basin without
surface outlet, has its longer axis on L street, N. W., between Vermont
avenue and 23d street, a length of about $\frac{9}{10}$ of a mile, and has a mean
breadth of about $\frac{1}{4}$ of a mile.   The rim of this basin has an elevation of
60 feet above tide, and the lowest point within it is 12.3 feet below the
rim.   The steep slopes on the north and south of the basin send down
the rain-fall rapidly towards it; and while existing sewers were gorged,
the water accumulated to the depth of $4\frac{1}{2}$ feet upon the surface.   Be-
tween this basin and Boundary street on the north, were, originally, the
slashes and the deep valley of Slash Run.   These have been filled by in-
tersecting streets to a depth varying from 4 to 40 feet, leaving numerous

squares without surface outlet, and so far below street grades that owners opposed, with violence, any proposition to bring them to grade. This is known as the Slash Run District. Another depression extends from 17th street west to the foot of Capitol Hill, the rim of the basin being 10 feet above tide, and the lowest point (about at the middle of this area) 3.4 feet below the rim. It is about $1\frac{4}{10}$ miles long and 1 000 feet wide. It is separated by a low divide from another depression, extending southward about $1\frac{4}{10}$ miles to the Eastern Branch and tapped by the James Creek Canal.

Through these low grounds the two principal main sewers of Washington discharge into the Potomac, receiving from them numerous tributary drains, which are quickly affected by back water in the main sewers. It will be seen that the principal thoroughfare of Washington (Pennsylvania Avenue) follows the northern boundary of this area, which occupies the central part of Washington City. The ground falls precipitously from the summit, 320 feet above tide, to the city limits, and quite rapidly through the city to the low grounds. In descending to the boundary of this low area, only two-thirds of the distance to the Potomac is accomplished, and 310 feet of head are lost, leaving only 10 feet with which to accomplish the remaining third of this distance. The natural surface of Washington and vicinity is generally a stiff retentive clay, which is almost impervious to water. In laying pavements, "wet holes" in this material have to be dug out and refilled with dry earth, because water would never escape from them. The street pavements are of stone blocks with tarred joints, coal-tar concretes, and asphalt; the latter are preferred wherever it can be advantageously put down, and all are practically water-proof.

METEOROLOGY.—The records of the Smithsonian Institute, of the Naval Observatory and of the Signal Service, are available for the determination of rain-fall. The latter contains the continuous curve record of a self-registering rain-gauge from 1871 to the present time, giving the intensity and duration of down-pours with the detailed phenomena of all storms. From these sources and principally from the self-registering rain-gauge of the Signal Service, it is found that the following rain-falls are to be expected in the District of Columbia :

TABLE of actual intensity and duration of rain-fall in the District of Columbia:

Duration in hours	0.083	0.133	0.250	0.333	0.366	0.416	0.500	0.666	0.750	1.25	3.25	56.00
Rate in inches, per hour	6.24	3.53	3.00	2.22	2.65	4.27	2.28	3.00	1.52	1.00	1.51	0.14

In Philadelphia, Pa., a rate of 3 inches per hour has continued two hours; in Norristown, Pa., a rate of 1.8 inches per hour has continued five hours.   The proximity of these localities to the District of Columbia and the similarity of meteorological conditions, suggests that these observations be included with those in the District of Columbia, which cover only a very limited period of time.   These observations are all plotted on Plate XIII.

This record being mainly that of a single rain-gauge, the area covered by the several precipitations cannot be stated.   It is inferred from the effect, at times, upon the several drainage areas that they may cover from 5 to 50 square miles, if not more.   The principal freshets of the Potomac occur from February to April.   Violent rain storms in the District of Columbia occur, usually, between July and October, both months inclusive, and they are more apt to occur in one or the other of these months, rarely much earlier than July or later than October. Freshet and local storm will, therefore, rarely coincide.   Violent precipitation will seldom occur upon frozen or icy surfaces, but immunity from this cannot be depended upon; and this is not important, as the growth of the city will cover all natural surface which drains through it now.

PROPORTIONAL OUTFLOW OF STORM WATER.—In the absence of exact determination of areas covered by individual storms, the total precipitation upon any drainage area cannot be ascertained and the precise relation between rain-fall and outflow cannot be traced.   It has been found, however, that when the gauge at the Signal Office registered a rainfall of 1.78 inches in twenty-five minutes, an area of 436 acres, in which the Signal Office occupied a central position, and which is mainly paved and built up, gave a maximum rate of outflow between 2 and 4 inches per hour; the main drain with a capacity of 2 inches per hour, running under a high head, and a large quantity of storm water escaping over the surface.   The gauging of the main drain of the same area in 1885, at a point where it receives the drainage of 200 acres, paved with asphalt and well built up, indicated no appreciable loss during the period of maximum flow when the rain-gauge gave a precipitation of 0.55 of an inch in thirty-seven minutes, the rate of outflow being exactly the rate of rain-fall.   When the rain-gauge gave a precipitation of ½ inch in fifteen minutes, a rate of 2 inches per hour, the maximum rate of outflow in the drain was three-quarters of the rate of rain-fall, or 1½ inches per hour.   Gauging the original main sewers

was, generally, of little use, because when not gorged the rainfall was insignificant, and when gorged by heavy rains the proportion escaping over the surface could not be measured.   Tiber sewer was destroyed when discharging about 3 000 cubic feet per second, but the record is complicated with pondage, overflow, and partial diversion of the storm water.   Upon another occasion the water-ram in the easterly main branch of this sewer, 9½ feet in diameter, ruptured the branch sewer, throwing a fragment of the arch weighing several hundred pounds over a distance of 50 feet.

PLANS.—On the topographical sketch, Plate XII, are shown the three principal original main sewers.   To relieve these the principle of interception was adopted; the relieving sewers also shown being designed to carry, without risk of failure, all surface water flowing from the respective areas above them.   To harmonize with the existing system they were designed as sewer drains, having generally an oval shape, excepting that section of the intercepting storm sewer on Boundary street, between the point A and the Eastern Branch.   It was decided that sewage should not be taken toward the Eastern Branch because of its unimproved channel and of the wide marshes on either side which might wait long before reclamation.   For this reason the whole line from 14th street to the Eastern Branch was at first designed as a storm conduit or overflow sewer.   The plan was subsequently modified to make this line a sewer-drain as far as point A.

The computation of capacity for the relieving sewers and their lateral branches assumed a maximum rain-fall of 3 inches per hour (the rate which ruptured the old Tiber sewer) and a maximum outflow of two-thirds of this, or 2 inches per hour. It was known that with this assumption the smaller sizes of main sewer must run, at times, under a head, being then subjected to an internal pressure, which they were fitted to sustain; but it was thought this would never occur where the sewers were of a size to make such pressure dangerous—the factor of safety increasing with the size of the sewer, or with the quantity of water carried, and therefore with the relative importance of this consideration.   These sewers having to supplement to the best advantage an existing system, required, each, a special study.   The general considerations have been given at length hereinbefore.   The details of all would be tedious, and the largest of these, the main sewer in Boundary street, between 14th street west and the Eastern Branch, will serve as an illustration.

BOUNDARY INTERCEPTING STORM SEWER.—This was designed with a

minor drain on Maryland avenue for the relief of Tiber sewer, to take from it all of its drainage area except about 1 500 acres. The diversion of the drainage of this area leaves the Tiber sewer subject to a second catastrophe, by the same conditions which caused the first one, if it should ever be required to discharge from its remaining drainage area the maximum flow assumed of 2 inches per hour, or two-thirds of the rate of rainfall which ruptured it (3 inches per hour). The line of Boundary street crosses the outlet valley of the precipitous area to the north of the city with a high embankment. On this line is constructed the boundary intercepting sewer.

A glance at the map shows that Washington is hemmed in on the south by the Potomac, on the east by the marshes of the Eastern Branch, and on the west by the deep gorge of Rock Creek Valley. It can expand only northward over the area drained by the boundary intercepting sewer. Soldiers' Home Park, Glenwood Cemetery and the new reservoir occupy about 660 acres of this, upon the highest ground. The precipitous slopes of the park   n give no pondage, and its stiff soil but little absorption. The well-kept walks and drives permit the rapid discharge of storm water. The park may resist the encroachment of the city, or it may melt away in time as other military reservations have done under similar circumstances. The cemetery, of course, must go sooner or later. Here are found the finest building sites in the District of Columbia. Over the greater part of this entire area, which is already to a great extent subdivided and occupied by suburban residences, the impervious roofs and pavements of Washington will eventually extend. Having steeper slopes, there will be a more rapid discharge of storm water than obtains anywhere within the present city limits. In addition to this suburban property it was necessary to divert into Boundary sewer the drainage of a large city area between 14th, O and Boundary streets by a main sewer along O street. It will be noticed that the O street sewer, the main artery of this area, crosses a deep depression, the former valley of Tiber Creek, to reach the Boundary sewer. To prevent back flow in the former, it was necessary to keep the level of storm flow in the latter as low as possible. Here came a serious difficulty. The great depth of excavation and the character of the ground which former excavation had shown would be encountered, together with the necessarily great size of the Boundary sewer, developed

a complicated question—the proper form and size to be given to this great main drain to satisfy all existing conditions.

At the point A this question was presented, where a concentration of flow occurs, which continues without material change to D. The rapid convergence to this point of the drainage lines of its four principal sub-areas is indicated by the sketch. The surface of the first sub-area falls from the summit, 320 feet above tide, to 60 feet above tide at A in a distance of about 13 200 feet, having a general slope of 19.69 feet per thousand, and draining about 1 016 acres. The surface of the second sub-area falls from the same summit to 70 feet above tide at B in a distance of 11 800 feet, having a general slope of 21.18 feet per thousand, and draining about 915 acres; from this point it continues to A through Boundary sewer. The surface of the third sub-area falls from 220 feet above tide to 88.5 feet above tide at C in a distance of 6 300 feet, having a general slope of 20.87 feet per thousand, and draining about 320 acres; from this point it continues to A through Boundary sewer. The fourth sub-area is that within the city limits; the surface falls from 127 feet above tide at 14th and Boundary, to 60 feet above tide at the point A, in a distance of 9 100 feet, having a general slope of 7.36 feet per thousand, and an area of 485 acres. In each case the natural drainage lines are but little longer than the air line distances given above. The aggregate of these four sub-areas gives an extent of water-shed tributary to Boundary sewer at the point A of rather less than $4\frac{1}{2}$ square miles. This is less than the probable area covered by the down-pour of June 28th, 1881, giving a rate of precipitation of 4.23 inches per hour; it is much less than the probable area covered by the down-pour of August 5th, 1878, giving a rate of precipitation of 3 inches per hour for forty minutes. The surface slope in feet per thousand in these several sub-areas ranges from 0.92 to 2.64 times the slope in the 200-acre paved area of New York avenue sewer, which gave by gauging a maximum rate of outflow equal to the maximum rate of precipitation. The character of the surface of these sub-areas will eventually be nearly the same as that of the New York avenue area, and must sooner or later combine with their steeper slopes to produce the same results.

A mean velocity of 6 feet per second would bring to A the rain-fall upon the point most remote from A in forty minutes. In that time a storm covering the $4\frac{1}{2}$ square miles of territory in the four sub-areas

draining to A would therefore develop its maximum effect at A; the maximum flood wave at A receiving then, a simultaneous contribution from every point within this water-shed. It was a rain-fall of 2 inches in forty minutes, a rate of 3 inches per hour, that destroyed the Tiber sewer, the relief of which is sought by the construction of the Boundary sewer. It was evident that the maximum capacity here must not be less than elsewhere in the new system. This fixed the maximum capacity at two-thirds the maximum rate of rain-fall assumed (3 inches per hour) ; and the existing conditions of slope, etc., gave by Kutter's formula a conduit of a circular cross-section and 20 feet diameter, for conveying this maximum flow.

All of the foregoing applies with even greater force to the smaller sections of Boundary sewer above the point A. At this point other important considerations present themselves. This section of Boundary sewer, at the grade adopted, requires an average depth of excavation of 45 feet, reaching at one point, near the point A, a maximum depth of 50 feet. Had it been assumed that the full capacity would be required except at long intervals for phenomenal storms, the sewer must have been laid about 10 feet deeper at A, with increased section to compensate for the diminished slope, in order to keep the surface of flood-flow below the danger line for the O street sewer. The depth was fixed by the assumption that the ordinary and even extraordinary maximum flood-flow would be one-third of the maximum rate of rain-fall, and would be carried in a semicircular conduit, the flood surface being at the spring line of the arch. The semicircular section gives the maximum sectional area adapted to variable flow, with the minimum height of flood surface, for ordinary storms. A factor of safety of two is given by the additional space between the spring line and the soffit of the covering arch, but does not cover the safety of the O street area. This must be jeopardized by any lifting of the ordinary flood surface above the level assigned to it. At the grade adopted, this section of Boundary sewer is constructed, as foreseen, throughout nearly its entire length in a stratum of fine white sand, which becomes quick sand when complicated with pockets of water, but is firm enough when undisturbed. The thrust is taken, generally, by this material, which would be a treacherous backing under frequently varying conditions of saturation of the sand and internal stress in the sewer. The construction is indicated in the diagram. See Plate XIV.

Such a large masonry conduit, in such a formation, at great depth, depends for its safety upon being undisturbed, and this assurance it is intended to give with the factor of safety adopted.   To illustrate: suppose that the maximum capacity were reduced to, say, six-tenths of that assumed, the conduit receiving a semicircular invert of 15 feet diameter and an interior height of 17½ feet. Such a conduit would be taxed to its utmost capacity by a maximum outflow about one-fifth greater than would be carried in the invert of the larger conduit.   With a greater outflow the smaller conduit must run under a head, becoming a forced conduit.

Conduits running full-bore are subjected to an outward pressure, due to the contained water, which increases as the vertical diameter and the perimeter of the conduit. The dangerous feature of this hydrostatic rupturing pressure is not, ordinarily, the lifting effect upon the arch, but the horizontal thrust which induces a spreading at the springing line and a depression at the key. It is by such deformation that masonry conduits fail when the arch is heavily loaded and the thrust passes out into a yielding ground. The tendency of this hydrostatic pressure is to reinforce the thrust of the arch. Under the conditions stated, this conduit is subjected to dangerous strains whenever the flood surface rises above the springing line of the arch. If it run only full bore it will sustain a hydrostatic pressure of about 14 tons per lineal foot; or over a section of 20 feet, behind which a cavity might form, a fluctuating pressure reaching 280 tons. If run under a head, the pressure is greater, and the fluctuating storm wave will develop the much more dangerous water-ram. A too frequent hammering of this kind is a matter for grave consideration in such a structure at great depth in a sand formation, and more especially if a mistaken economy be permitted to reduce the thickness of arch or invert. A conduit designed to run full-bore in ordinary storms is habitually exposed to both these sources of danger, whereas another of such capacity that the fluctuations of surface flow in ordinary storms are kept within the limits of the invert, will incur less danger in phenomenal storms at long intervals. It is perhaps unnecessary to show that such a diminution in size of conduit would defeat the principal object secured by the larger conduit—the lowering of the flood surface and the conveyance of ordinary storms in the channel of maximum sectional area adapted to variable flow, with minimum height of flood sur-

face. A storm that would carry the flood surface in the larger conduit
to the danger line for the O street area, would carry it 6½ feet above
that line in the lesser conduit.

The area drained by Boundary sewer at the point *A* and the area
remaining to Tiber sewer, aggregate 6.7 square miles. A storm covering
this combined area would tax simultaneously the capacity of each, and
if Boundary sewer fail, Tiber sewer must take the consequences. It
has been already explained that disaster will follow if the rate of flow in
Tiber sewer equal two-thirds the rate of rain-fall which ruptured it in
1878.   The Nagpoor, India, storage reservoir (see *ante*) receives the
flow from a water-shed of 6.6 square miles, an area almost identical
with the combined area drained by Boundary and Tiber sewers. With a
very absorbent natural surface, that water-shed has nevertheless delivered
to the reservoir in one hundred and seventy minutes, 98 per cent. of a
down-pour upon its entire area of $2\frac{2}{10}$ inches in eighty minutes, when the
power of absorption of the soil had been satisfied. From this may be
inferred the effect upon the area drained by Boundary and Tiber sewers,
when the greater part of this area, including the steep slopes of the former,
is covered by waterproof artificial surfaces, of a precipitation of nearly
the same quantity of rain-fall (2 inches) in one-half the time (forty
minutes) to which it has been subjected quite recently. It must be
subjected to storms of even greater violence and duration. The im-
potency of empirical formulas to deal with this question may be seen
in their application to the New York avenue intercepting sewer (see
ante).   The impropriety of petty economy in the design of this work,
which closely affects the interests of nearly 7 square miles of valuable
property, appears quite clearly in the record of the work it is designed to
supplement.*

On the 5th of August, 1878, a rain-fall of 2 inches in forty minutes
occurred in the District of Columbia, a rate of 3 inches per hour. It
ruptured the largest main sewer of Washington—the old Tiber Arch.
For a distance of 500 feet the brick arch, 18 inches in thickness, and
having a span of 30 feet, was lifted bodily and broken at the haunches
and at the crown. Fortunately it fell with the subsiding water into
place again, the fractured edges projecting half way into the sewer.
The sectional area of Tiber sewer is here 220 square feet. If the arch

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* See Report of Commissioners, D. C., for 1878.

DETAILS OF THE SEWERS OF WASHINGTON. SEE DIAGRAM, PLATE XIV.

	1 (1)	1 (2)	1 (3)	1 (4)	2 (5)	2 (6)	2 (7)	2 (8)	2 (9)
No. of diagram. No. of reference									
Interior dimensions	12"	15"	18"	24"	2'x3'	2'3"x3'4.5"	2'6"x3'9"	2'9"x4'1.5"	30'x4'6"
Relative capacity	1	1.84	3.05	6.68	10.81	15.17	19.4	26.51	32.46
Relative cost	1	1.15	1.40	2.04	2.70	3.00	3.15	3.33	3.57
Average depth of excavation	10'6'	10'6'	10'6'	10'6'	12'6"	12'9"	13'0"	13'3"	13'6"
Sectional area, square feet	.785	1.227	1.767	3.140	4.64	5.92	7.23	8.71	10.41
Perimeter, lineal feet	3.14	3.92	4.71	6.28	8.17	9.12	10.33	11.07	12.14
Hydraulic radius	.25	.31	.375	.50	.567	.649	.70	.787	.887
Diameter of corresponding circular sewer	......	......	......	......	2.27	2.60	2.80	3.15	3.43
ITEMIZED QUANTITIES PER LINEAL FOOT:									
Cubic feet, brick work	1.57	1.96	2.32	3.07	4.70	5.13	5.63	5.95	6.60
Cubic feet, concrete	......	......			4.45	4.60	4.75	5.00	5.24
Square feet, trap rock	......	......			12"	16"	15"	15"	15"
Diameter pipe invert	......	......			1.80	2.00	2.10	2.30	2.40
Cubic yards excavation	1.00	1.10	1.30	1.40	.52	.59	.67	.74	.83
Cubic yards surplus earth	.100	.13	.18	.27					
ITEMIZED COST PER LINEAL FOOT:									
Brick work	.29	.36	.43	.57	$1 39	$ 1 53	$1 67	$1 76	$1 95
Concrete	......	......			82	85	88	92	97
Trap rock	......	......							
Pipe with connections and manholes	......	......	.76	1 30	.10	10	10	10	10
Pipe invert	......	......			25	33	33	33	33
Excavation and refilling	.40	.44	.48	.56	63	70	73	80	84
Surplus earth removed	.02	.02	.03	.04	07	09	10	12	13
*Total cost	$1 21	$1 38	$1 70	$2 47	$3 26	$3 60	$3 81	$4 03	$4 32
Increased cost of ramming earth	16	17	18	22	27	27	27	28	28
Aggregate cost	1 37	1 55	1 88	2 69	3 53	3 87	4 08	4 31	4 60

* In case of paved streets the cost of repaving is to be added.

DETAILS OF THE SEWERS OF WASHINGTON. SEE DIAGRAM.—*(Continued.)*

	2 (10)	2 (11)	2 (12)	2 (13)	3 (14)	3 (15)	3 (16)	3 (17)	3 (18)
No. of Diagram, No. of Reference. Interior Dimensions	3'3"x4'10.5"	3'6"x5'3"	3'9"x5'7.5"	4'0"x6'0"	3'3"x4'10.5"	3'9"x5'7.5"	4'0"x6'0"	4'6"x6'9"	5'0"x7'6"
Relative capacity	40.15	40.29	60.42	70.69	40.13	59.05	70.13	95.75	126.44
Relative cost	3.89	4.14	4.40	4.71	4.19	4.80	5.16	5.67	6.15
Average depth of excavation	13'09"	14'00"	14'03"	14'06"	14'03"	14'09"	15'00"	15'06"	16'00"
Sectional area, square feet	12.13	14.18	16.50	18.63	12.12	16.16	18.38	23.26	28.71
Perimeter, lineal feet	12.95	13.95	15.07	16.10	12.88	14.86	15.85	17.84	19.82
Hydraulic radius	.937	1.01	1.09	1.16	.94	1.087	1.16	1.30	1.45
Diameter of corresponding circular sewer	3.75	4.04	4.36	4.60	3.76	4.348	4.64	5.20	5.80
ITEMIZED QUANTITIES PER LINEAL FOOT:									
Cubic feet, brick work	7.14	7.68	8.25	8.65	6.39	7.20	7.60	8.00	8.65
Cubic feet, concrete	5.41	5.81	6.06	6.45	4.21	5.300	6.00	6.70	7.33
Square feet, trap rock					3.38	3.73	4.00	4.50	5.31
Diameter pipe invert	18"	18"	18"	20"					
Cubic yards excavation	2.60	2.80	3.00	3.20	2.60	3.00	3.20	3.60	4.00
Cubic yards surplus earth	.92	1.00	1.15	1.26	.93	1.13	1.30	1.47	1.82
ITEMIZED COST PER LINEAL FOOT:									
Brick work	$2 11	$2 27	$2 44	$2 66	$1 89	$2 13	$2 25	$2 37	$2 66
Concrete	1 00	1 07	1 12	1 19	78	98	1 11	1 24	1 35
Trap rock					1 25	1 38	1 48	1 67	1 96
Pipe with connections and manholes	10	10	10	10	10	10	10	10	10
Pipe invert	44	44	44	55					
Excavation and refilling	91	98	1 05	1 12	91	1 05	1 12	1 26	1 30
Surplus earth removed	14	15	17	19	14	17	19	22	27
Total cost	$4 70	$5 01	$5 32	$5 71	$5 07	$5 81	$6 25	$6 86	$7 44
Increased cost of ramming earth	28	29	29	31	28	28	31	32	33
Aggregate cost	4 98	5 30	5 61	6 02	5 35	6 09	6 56	7 18	7 77

DETAILS OF THE SEWERS OF WASHINGTON. SEE DIAGRAM.—(*Continued.*)

No. of diagram. No. of reference	3 (19)	3 (20)	3 (21)	4 (22)	4 (23)	4 (24)	5 (25)	4 (26)	4 (27)
Interior dimensions	5'06"x28'03"	6'0"x9'0"	7'0"x10'6"	7'6"	8'3"	13'2"	20'0"	20'0"	22'0"
Relative capacity	163.13	205.89	309.25	231.02	302.49	1013.82	3016.73	3016.73	3861.48
Relative cost	7.0	9.19	10.87	9.73	12.94	22.45	50.25	50.92	50.91
Average depth of excavation	166"	170"	180"	195"	159"	231'04"	43'02"	32'2"	23'2"
Sectional area, square feet	34.74	41.35	56.27	44.18	53.46	136.16	314.16	314.16	380.13
Perimeter, lineal feet	21.80	23.79	27.75	23.56	26.92	41.36	62.83	62.83	69.11
Hydraulic radius	1.59	1.738	2.027	1.875	2.062	3.290	5.00	5.00	5.50
Diameter of corresponding circular sewer	6.36	6.952	8.108						
ITEMIZED QUANTITIES, PER LINEAL FOOT:									
Cubic feet, brick work	10.43	15.00	17.16	12.68	18.40	37.92	58.21	95.17	104.49
Cubic feet, concrete	8.45	12.83	14.73	16.45	17.15	26.45	135.27	68.31	73.17
Square feet, trap rock	5.56	6.08	7.77	8.11	12.96	11.85	16.44	16.44	17.14
Diameter pipe invert									
Cubic yards, excavation	4.40	5.20	6.20	5.80	6.40	19.00	70.00	4.40	30.00
Cubic yards, surplus earth	2.16	2.75	3.45	2.94	3.62	7.75	16.20	16.20	18.90
ITEMIZED COST, PER LINEAL FOOT:									
Brick work	$3 09	$4 44	$5 08	$3 76	$5 45	$11 23	$8 36	$28 19	$30 96
Concrete	1 56	2 37	2 72	2 74	2 86	4 41	22 54	11 38	12 19
Trap rock	2 06	2 25	2 87	3 00	4 79	4 38	6 08	6 08	6 34
Pipe, with connections and manholes	10	10	10	10	10	28	40	33	28
Pipe invert									
Excavation and refilling	1 32	1 66	1 86	1 74	1 92	5 70	21 00	13 20	9 00
Surplus earth removed	32	41	52	43	54	1 17	2 43	2 43	2 83
*Total cost	$8 45	$11 13	$13 15	$11 77	$15 66	$27 17	$60 81	$61 61	$61 60
Increased cost of ramming earth	39	40	46	46	50	2 02	9 68	5 67	2 00
Aggregate cost	8 84	11 53	13 61	12 23	16 16	29 19	70 49	67 28	63 60

* In case of paved streets the cost of repaving is to be added.

The following prices have been assumed: Excavation and refilling, 40 cents per cubic yard from case (1) to (5); 35 cents per cubic yard from (5) to (18); 30 cents per cubic yard from (18) to (27). Hauling surplus earth, 15 cents per cubic yard. Brick masonry, $8 per cubic foot. Concrete, $4.50 per cubic yard. Trap rock, 37 cents per square foot. In cases (24), (25), (26) and (27), excavation is measured allowing a slope of .1 foot horizontal to 2 feet vertical from springing line to surface, and average depths in (25), (26) and (27), as constructed.

had fallen in and obstructed the water-way, a torrent of 3 000 cubic feet per second would have been thrown upon Pennsylvania avenue. The cost of this work was about $108 per lineal foot. In this single instance $54 000 worth of mistaken economy was swept away in forty minutes. Tiber sewer had been but two years completed, but the cost of the section destroyed is insignificant when compared with the destruction and depreciation of property which this sewer had already effected.

DISCUSSION.

J. Foster Flagg, M. Am. Soc. C. E.—In a visit to the Caribbee Islands in the early part of 1885, the writer learned of a remarkable fall of rain that occurred in St. Kitts in January, 1880, and took some pains to investigate it and verify the accounts given of it. The rain-fall was of such a phenomenal character, so much exceeding any other that he had seen recorded, that it seemed to him worthy of record in the *Transactions* of the Society in connection with the valuable paper of Mr. Hoxie upon this subject. This outpour from the clouds, in which it would seem as if the water must have fallen by bucketfuls instead of in drops, partook, apparently, of the nature of the "cloud-bursts" of our western States, as they are there termed, but extended over a larger area than probably is common in the latter; it certainly was not a waterspout, as the excessive fall of rain was noted over an area of several square miles at least (a good authority estimates the area of intense rain-fall as 6 or 8 miles square). There was a light rain in the evening of the night on which the down-pour took place, but none of consequence before 10 or 11 P.M.; and before daybreak—by 5 A.M.—it was all over. There were no rain gauges—any ordinary ones in fact would have been entirely useless, but a tank with vertical sides, used in sugar making, at a sugar estate near the town of Basse Terre and the south coast of the island, which was known to have been empty before the rain took place, and which was 30 inches deep, was filled and running over; the tank was lying out of doors where it could have received no other water except that falling directly into it from the clouds. One intelligent informant said that at a low estimate 36 inches of rain must have fallen; the evidence is positive that over 30 inches fell, most of it in about six hours, and all in ten or eleven hours. At another sugar estate, on the opposite or northerly side of the island, 4 or 5 miles away in an air line, and with a mountain some 3 000 feet high intervening, a similar sugar tank (or copper), empty the night before, had 23 inches of rain-fall in it the following morning.

TOPOGRAPHICAL SKETCH
OF
WASHINGTON, D. C. AND
VICINITY.
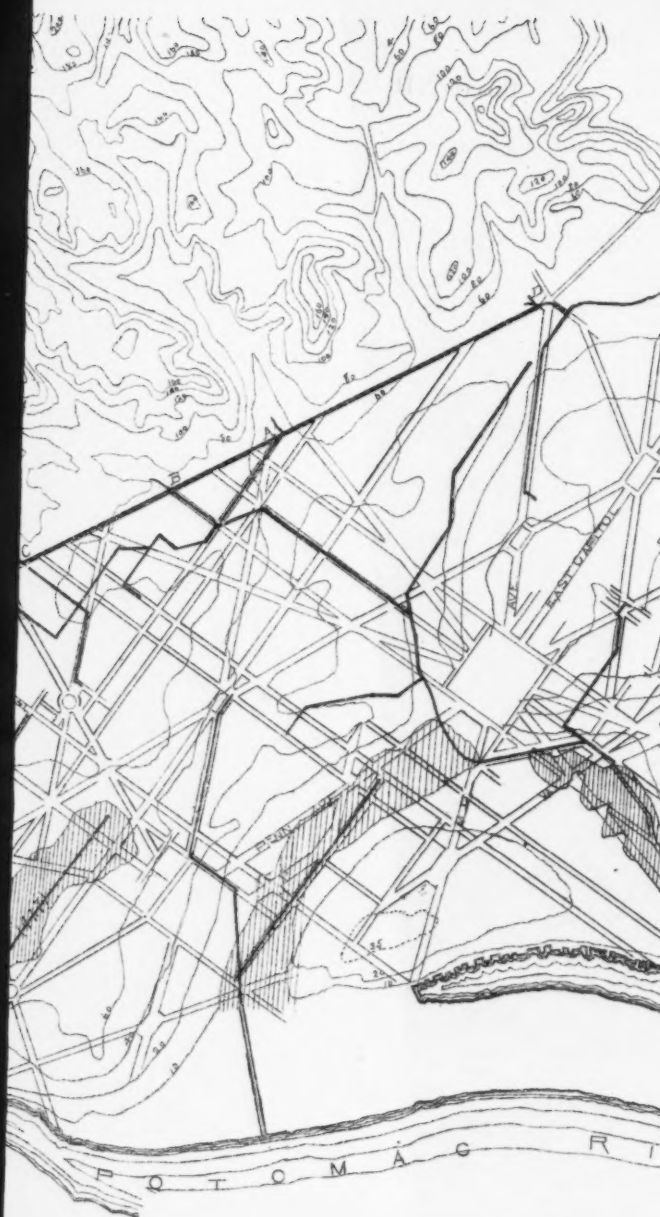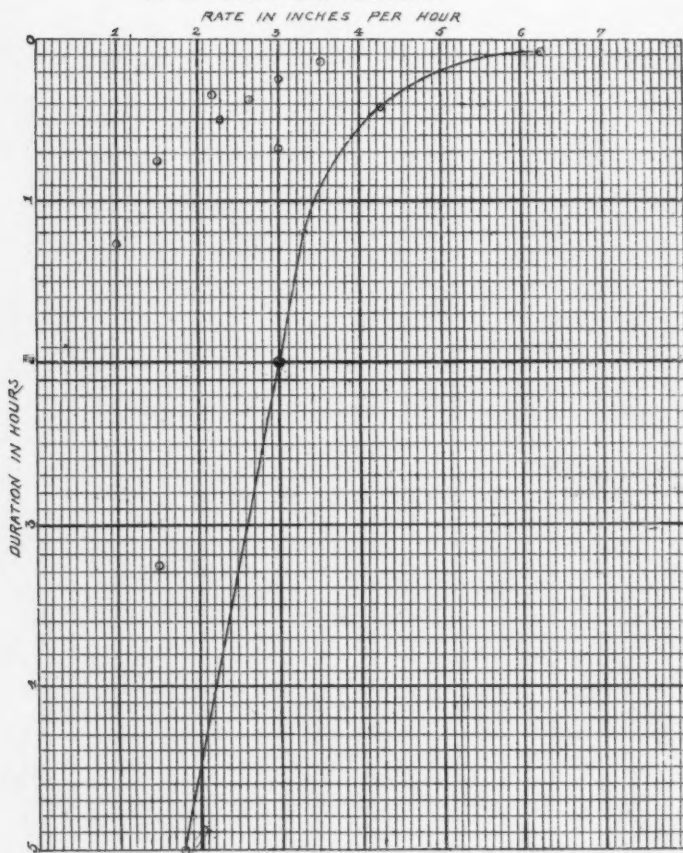SHOWING DRAINAGE LINES OF ALL TERRITORY
DRAINING THROUGH THE CITY.

1883.

P O T O M
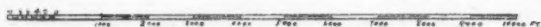
PLATE XII
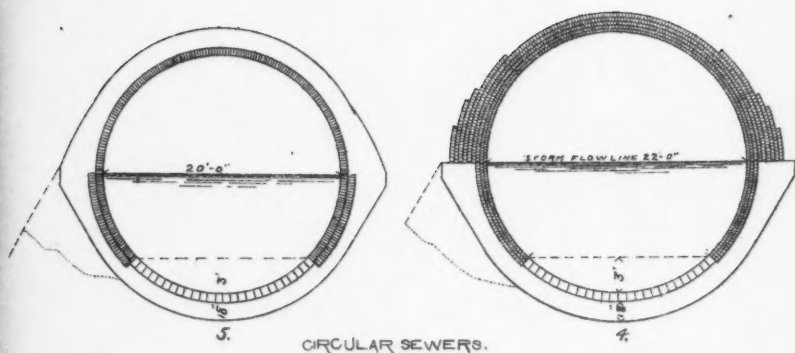TRANS.AM.SOC.CIV.ENG'RS.
VOL.XXV. N⁰ 489.
HOXIE ON
EXCESSIVE RAINFALLS.

DIAGRAM OF MEAN INTENSITY OF HEAVIEST
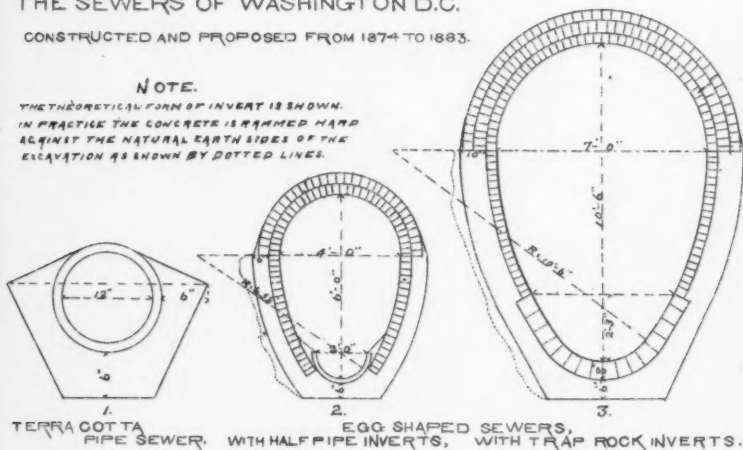DOWN-POURS, PLOTTED FROM OBSERVATIONS
IN THE DISTRICT OF COLUMBIA.

20'-0"

STORM FLOW LINE 22'-0"

5. CIRCULAR SEWERS. 4.

THE SEWERS OF WASHINGTON D.C.

CONSTRUCTED AND PROPOSED FROM 1874 TO 1883.

NOTE.

THE THEORETICAL FORM OF INVERT IS SHOWN.
IN PRACTICE THE CONCRETE IS RAMMED HARD
AGAINST THE NATURAL EARTH SIDES OF THE
EXCAVATION AS SHOWN BY DOTTED LINES.

7'-0"

4'-0"

6'-0"

R-10"-0"

1. 2. 3.
TERRA COTTA   EGG SHAPED SEWERS,
PIPE SEWER. WITH HALF PIPE INVERTS, WITH TRAP ROCK INVERTS.

The destructive effects of the storm upon the little town of Basse Terre, the capital of the island, are strongly corroborative of the direct evidence as to the magnitude of the rain-fall. The town is built on a plain along the shore, having a slight slope upwards away from the sea, and also in an easterly direction on the line of the shore. It has little depth from the sea in proportion to its length, and has a number of streets running down towards the shore; there is no semblance of a hill or valley on either side of the town. But in the rear of the town, a half or three quarters of a mile away, Monkey hill rises sharply up from the plain to an altitude of 1 150 feet—so sharply and with so little extent to its summit that the whole hill covers but little area on the plain. It is nearly isolated, connecting by a "hog back" with Mt. Olivees (over 3 000 feet high) a portion of the ridge which forms the backbone of the island. The whole island has an area of only 68 square miles, and but a small portion of it (perhaps 5 or 6 square miles) drains more or less in the direction of Basse Terre, though with no defined water-course. From the precipitous character of the mountainous water-shed, however, nearly the entire amount of the rain falling upon it that night must have been delivered rapidly upon the ill-fated town. Notwithstanding the shortness of the streets debouching upon the bay, and their number, the streets were filled with a torrent in places over 8 feet deep. Several of the smaller houses were swept down the streets and out to sea, and larger ones carried from their foundations into the streets. Over 200 persons were drowned, a large number being carried out to sea. Such a torrent naturally brought down with it a large amount of detritus; and in the public garden, a square of 450 feet each way, the northern half was filled with mud to a depth of 4 or 5 feet, entirely covering the fence surrounding it (the water was 6 to 8 feet deep in the square). In fact the following morning a woman was dug out of the mud who had been caught as she was attemping to cross the square, and buried upright as she stood, the top of her head alone showing. This square is only 225 feet from the open shore, with two streets respectively 30 and 33 feet wide leading from it directly to the beach. Two streets of similar width enter it from the land side, and two entering it (one at the the lower end) run parallel with the shore. If the town had been situated in a narrow valley one can readily understand how the water would have risen even to a much greater height; but with its numerous streets emptying directly into the open sea the height of the torrent therein was something marvelous, and indicates plainly the extraordinary nature of the rain-fall.

WILLIAM RUMBLE, M. Am. Soc. C. E.—I find among my old papers a record of rain-fall at Morrisania, of which the following is a copy:

OCTOBER 30th, 1866.
Rained most of previous night. From 7.45 A.M. until 9.15 A.M. the amount of rain-fall was 1.73 inches, being at the rate of 1.15 per hour.
At 10 A.M. there was running in Mill Brook at the railroad crossing,

near 3d street, 100 cubic feet per second, equals 360 000 cubic feet per hour.

The area of Mill Brook water-shed, above the point of measurement. is about 1 790 acres, and the amount of rain-fall on the same at the above rate will equal 7 472 355 cubic feet in an hour—showing the amount running in the stream to be about 4½ per cent. of the rain-fall per hour.

Mr. R. E. McMath, M. Am. Soc. C. E.—I think that this Society ought to take steps to arrive at some definite information as to the necessary sizes for sewers, and that definite information I think could be obtained by getting together the experience which the different members of this Society have in their own possession. Now, in the City of St. Louis we have to do with this question of the maximum rain-fall, because the topography of our city is such that we have numerous depressed basins which have no natural outlet, and we must provide for the greatest quantity of water which will fall, and carry it off as rapidly as it reaches the sewers. We have those depressed basins ranging from fifty acres up to one thousand. We have one containing six hundred acres. We had a rain-fall on the 14th of May last of $3\frac{7}{10}$ inches, falling wholly within two hours, the greater part of it within forty minutes. By tabulating the sizes of the sewers, and their gradients on the areas which are graded at different parts of the length, and by considering the fact that at certain portions of that length the sewers are overcharged, and at others there is no difficulty experienced, we have made a determination of the size and the gradient which will carry off the greatest rain-fall which occurs in that locality. This method was adopted in St. Louis in determining the size of sewers nine years ago. No sewer that has been built since that time has ever been overtaxed, and the sizes are based upon the expectation of carrying off 1 cubic foot of water per second for each acre drained.

The CHAIRMAN (R. B. STANTON, M. Am. Soc. C. E.).—I should like to relate to the Society an incident that happened here in Denver in the summer of 1885 of a kind which is not infrequent. Cloud-bursts occur very frequently at the head waters of Cherry Creek. This runs right through the city, but the area drained or any data in regard to it I cannot give. The particular flood occurring in 1885 was photographed during its height by Prof. Richards of the Polytechnic School of Boston, who happened to be here. He took a most excellent photograph of it. The clear water way of Cherry Creek is probably 90 feet in width. The bridges across it are all built 100 feet long, and this water came down in waves of 10 feet in height. Very frequently that creek is filled so that the crest of a wave will be 10 feet from the bed of the creek. Such a flood will come down without a moment's notice, and it would give rather an excessive amount of water to carry through a sewer.

A MEMBER.—Do those cloud-bursts ever occur in the lower part of the State? Has such a thing ever occurred here?

The CHAIRMAN.—Yes, sir, to a small extent; not anything like the

cloud-bursts that gather on the divide between the waters of the Platte and Arkansas Rivers.

Mr. GEORGE S. RICE, M. Am. Soc. C. E.—About four years ago I was in the southern part of Arizona, in Cochise County, and I noticed then the effect of one of these cloud-bursts, which are common there. There was a section of country about 2 000 feet long and about as wide. One afternoon a cloud-burst struck this particular spot, on the side of a hill. I was living in the vicinity and visited the spot afterwards. A stream of water from this cloud-burst rushed down in a body about 75 feet wide and about 2 feet high in the deepest place. This temporary stream passed within a short distance of a building made of adobe, and after it left this particular locality, which is about 5 000 feet above the level of the sea, it flowed down into a gulch where there were five or six adobe buildings, and they were swept completely away. That is the way these cloud-bursts sometimes happen, the rain seeming to drop right down from the sky.

Mr. THOMAS C. KEEFER, M. Am. Soc. C. E.—I would like to ask if the irrigation works in this vicinity have suffered from these cloud-bursts, or has special provision been made to meet them? Perhaps some gentleman here could tell us that.

The CHAIRMAN.—Very frequently they are washed away for large distances by cloud-bursts, and it takes a great deal of work to repair them and build them over. The ditch that supplies the City of Denver with water for its trees is washed away in that manner from five to six times in the year. If you will look at the article on the subject of irrigation in the pamphlet prepared for your information you will find some discussion on that very subject.

Mr. RICE.—I would like to relate another incident that I saw. I was located about 10 miles from Tombstone, and in the Tombstone district of Arizona. I attempted to keep a record of the rain-fall and of the temperature in that particular section. We had some alfalfa fields and were hoping that a rain would fall and help us in raising the crop, I noticed that for a week, in a section of country 5 or more miles in diameter, we had no rain, although the country around us had been plentifully supplied. Within this circle the dust was 3 to 4 inches deep on the roads, but go a few miles in any direction and you would find the effect of heavy rains. That is only an instance of how in the same locality you will have a great variation often in the rain that falls. I thought it was rather an interesting point to bring up, although it was not directly connected with this paper.

Mr. JOHN F. BARNARD, M. Am. Soc. C. E.—The trouble is that cloud-bursts take place when the parties are not there and there are no instruments to measure them. That is the trouble all through this country. You have a cloud-burst on the divide between here and the Arkansas, and the next one may be 50 or 100 miles in the other direction.

Mr. CHARLES LATIMER, M. Am. Soc. C. E.—I met one of the citizens of this State the other day, who is a railroad man, and he said that when he came to Salida there was no rain for cultivation, but that now good crops are raised very much farther west than Salida, and that the belt had extended 300 miles westward. Doubtless there must be statistics here which would either prove or disprove that. He was very positive of it.

Mr. ELIOT C. CLARKE, M. Am. Soc. C. E.—I have lately been a member of a commission appointed to design a conduit of sufficient capacity for carrying off the maximum flood from an area of about 12.7 square miles, in the vicinity of Boston. In considering the subject we examined the various formulas which profess to give maximum rates of flow from given areas. Among these formulas were most of those mentioned in the paper under discussion. The results given by the formulas varied from less than 600 cubic feet a second to nearly 6 000 cubic feet a second. In one case, evidently, no dependence could be placed on the formulas; and yet I suppose that all of them were derived from observation and experience, and, probably, each was applicable to the locality and conditions where it originated. Therefore I think that when such problems are to be solved we must not give too much weight to observations and results obtained elsewhere, but must study with great care the special conditions affecting the locality under consideration.

Mr. F. COLLINGWOOD, M. Am. Soc. C. E.—In reference to the question of extension of rain-fall, Dr. Newberry, of Columbia College, who has traveled very extensively over the plains making geological observations, says that that subject must be studied over a series of years or else very erroneous opinions will be formed. He says that you will find the forest area extending gradually for a number of years, trees growing where there were no trees before and evidence of fruitfulness, and yet there will surely come a series of dry seasons when you will find the whole edge of this forest absolutely killed, because of the lack of moisture, and the region will look almost as though burned by fire. Then the cycle will begin again. As apropos to this paper I would like to read the following extract from the Signal Service report for July, 1886:

"The following statement in reference to the exceptionally large rain-fall at Alexandria, Rapides Parish, Louisiana, on June 16th, 1886, is furnished by the observer at that place, in reply to a letter from this office asking the details:

"With reference to the heavy rain fall, it was correctly measured by me, as I watched the gauge closely; the rain seemed to concentrate and center in this particular vicinity, as the wind changed every forty-five or fifty minutes, sometimes more frequently. This town was eight-tenths flooded, in some portions water was 8 feet deep. The rain came down in sheets so heavy that the eye could penetrate but a short distance. The rain-fall from 5 P.M. June 15th, to 6.40 A.M. June 16th, was 11.09 inches; from 6.40 A.M. to 8.45 A.M. 2.16 inches; from 8.45 A.M. to 12.50

P.M., 8.15 inches; total for the nineteen hours and fifty minutes, 21.40 inches.''

Mr. JOHN F. BARNARD.—I think that the records which have been kept for a term of years show very conclusively that the rain-fall has been very steadily increasing and advancing westward. Seventeen years ago I came to the Mississippi River, and the country 100 miles west of that was supposed to be comparatively worthless. As settlers appeared and the ground was brought into cultivation, the soil that was loosened absorbed the rain-fall more and more; the subsequent cropping prevented rapid evaporation, and the moisture rose and formed clouds which otherwise would not have been. Showers fell where they had not fallen before, and then after a while these showers went over into the next county, and finally people went into the next county finding that they could raise good crops there; and so it extended. The records show that the rain-fall both in Kansas and Nebraska has very considerably increased, but more important than that, the rain falling and the moisture evaporating, it comes and goes more frequently. It is not as it used to be—a down-pour and then a dry spell. The rain-fall is distributed more evenly over the entire year. There is not a period of heavy rain-fall and then a long drought. That has been about the way it has been advancing as far as I have observed it for seventeen years. I have no doubt that the same influences will be brought to bear upon the eastern counties of Colorado. As Kansas is more cropped and as the soil is more completely stirred up I think the same results will follow. I think that the eastern borders of the State of Colorado will be affected in the same way, judging from the experience in Kansas and Nebraska. I might have prepared myself, if I had thought of it, with statistics from the authorities in the State of Nebraska, showing what the increased rain-fall has been from observations taken for fifteen or eighteen years.

Mr. JACOB BLICKENSDERFER, M. Am. Soc. C. E.—It is stated that the cultivation of the soil and the raising of crops in what was formerly a comparatively arid country, produces an increase of rain-fall. Well, I do not wish to call it in question, at least now; but I would like to ask, is the same observation true in other parts of the country as well as in these western States? Do the same causes produce likewise an increase of rain-fall, and if not, why not?

Mr. LATIMER.—I notice on the line of railroads with which I have had to do, that wherever you cut the trees off, it dries up the springs. In several cases we have had to abandon springs which were formerly very plentiful. The question would be, then, would it not be reasonable to suppose that if we plant trees we will hold the moisture in the ground, and then there would be the evaporation which would bring the water back again? As the former gentleman said, it is a well-known fact that by cultivation you break up the hard covering of the soil, which is like an adobe, and you will have an increased rain-fall all the time.

gentleman, the other day, speaking of the ditches around Denver, said it would have been a very excellent thing if the authorities in granting the right to make these irrigation ditches had required trees to be planted on both sides, as every tree that is planted increases the possibility or probability of rain-fall, or you might say the certainty of it.

The CHAIRMAN.—I wish to make one statement in connection with Mr. Blickensderfer's remarks. There is one fact noted in the cultivation of the plain through which you passed last night—that the cultivation of last year was the first in a large district, and this spring the crops planted on the soil that was broken up last year, prospered very well during the early part of this year, whereas the crops put in this year on new land were very largely killed; also that while there was no rain on that territory this spring, during a certain length of time, yet there was vastly more moisture in the ground broken up last year than in that broken up this year. This bears out the point that Mr. Blickensderfer presented—was the rain-fall increasing or was the moisture retained longer in the ground?

Mr. BLICKENSDERFER.—I confess to a good deal of skepticism as to the increase of the rain-fall by the cultivation of the soil. Of course, I may be mistaken, and I shall be very happy to be found to be mistaken, because, of course, this country would be benefited largely by an increase of rain-fall; but it seems to me we scarcely look over the ground with sufficient breadth to cover the whole question. While, of course, I admit it is much easier to ask questions than to answer them, I would like to ask whence comes our rain-fall? What is the original source of it, and unless that source is increasing, is the rain-fall increasing in the aggregate? Let us hear something on this subject. As to local observations, of course, we may expect oscillations. There is scarcely anything in nature that does not oscillate more or less. But that does not answer the question. We want to know whether there is a permanent advancement upon the whole or not; not whether there is an oscillatory movement that goes backward and forward and leaves us in the end where we were before. I will just state a matter that came to my knowledge when I was in Salt Lake Valley some years ago. I first made my acquaintance with that valley in 1868. The same question was then up in regard to Salt Lake Valley, and it was urged strongly, especially by those interested in the success of the valley, that the rain-fall was increasing; that it was constantly increasing; that crops could be raised on soil that would not produce a year ago, and as an evidence of increase was adduced, a fact that was undoubted, that the elevation of Salt Lake was constantly increasing. The water was rising. It was spreading over territory which some years ago had been uncovered. You will ask me for the facts. They were pointed out in this wise. "Here," said they, "you see that line of fence." "Yes, sir." "You observe the water is within a foot of the top of that?" "Yes, sir." "That fence was built

to inclose a meadow which the water did not reach by many hundred yards years ago. Now you see it is submerged, not only for a month, but gradually the water has been rising and coming up all the time since the settlement of the valley up to 1868; and is not that an evidence of an increase of rain-fall—that the rivers flow more water into the valley than they used to ?" Of course we had to admit it as far as it went. Still I own I was skeptical. I left Salt Lake Valley in 1869. I did not get into it again to become much acquainted with it until 1880. What was the condition then ? Salt Lake had gone on to rise for several years after I was there and attained an elevation of nearly 2 feet, or somewhere in that neighborhood higher than when I left, and now it was down almost as low as it was when the Mormons first settled. It has been gradually subsiding for the last few years, I believe, up to the present hour. Now, I do not know what the registers of the Smithsonian Institute give as the rain-fall in this series of years, nor do I know what they give in Nebraska, but while I will very readily admit that if you break up the soil it will preserve more of the rain-fall and convert more of it to useful effect in the production of crops than where there is a hard surface for it to run off, yet I confess still some skepticism as to an actual or permanent change in the record of the district.

One question I would like to have settled in that connection is the one I asked before—whence comes our precipitation, and what are the conditions that govern it now as compared with those that have governed it heretofore, or are likely to govern it hereafter ? As to the effect in the eastern States, it is an admitted fact, patent to every observer, that the denudation of the country of forests reduces the maximum flow of the streams in the summer season, and at the same time increases the maximum flow in times of flood, and it seems to me that it requires very little reflection to see why this is so. It is a fact patent which I can produce reasons for if you please. I know a certain place, for example, where floods in a large valley, one of the main affluents of the Muskingum River, have been registered since 1798; that is the excessive floods, and for twenty years every successive extreme flood has been a little higher than the previous one by the same permanent mark on a certain tree standing on the banks of the stream. Is there a change in the permanent precipitation ? I confess I doubt it.

MR. LATIMER.—As I understand it, there is no difference. There is just as much rain-fall, but it is diffused by the cultivation of the ground, and by holding the moisture in the ground. That is the point. When the ground is packed hard it will run off quickly. In some parts of the country, especially in Arizona, there have been immense territories which have been passed over for many years, people thinking that there was no water at all; and as I suppose the gentleman from Arizona knows very well, they have carried the water in wagons from 50 to 75 miles and sometimes 100 miles, imagining there was no water in

the country. Now, when the Atchison, Topeka and Santa Fé went through they found an abundance of water at 5 feet, but it was below a very hard surface.

A MEMBER.—Are we to understand from this that the rainless belt is not rainless—that water falls on it ?

Mr. RICE.—I would state in answer to the question just asked that it sometimes happens they have six and eight months without any rain. I have known an instance where we would have three weeks without a single cloud in the distance. They have their rain-fall in the summer time, generally in July, August and September. One year I recollect there was no rain from September until the following July. When it did rain it rained heavily, and there were cloud-bursts.

S. WHINERY, M. Am. Soc. C. E.—As a small contribution to the scanty statistics of excessive rain-falls, I submit the following from my own observation. At Somerset, Ky., about noon of August 12th, 1886, a sudden down-pour of rain occurred. The cloud appeared in the north-west and had passed around by the north to the northeast, but sud-denly veered and came up from that quarter, accompanied by heavy wind and thunder and lightning. From the beginning to the end of the shower was about thirty minutes. Total rain-fall, 1.57 inches. I es-timated at the time that fully four-fifths of this amount fell in twenty minutes, or at the rate of $3\frac{3}{4}$ inches per hour.

At the same place, on August 27th, 1886, about 3 P.M., a small rain-cloud came up from the northeast. It seemed to gather volume rapidly after the rain began falling. There was no breeze at first, but a strong wind soon sprang up from the northeast which veered around by south to the southwest. Total rain-fall, 1.18 inches. Duration of rain-fall, forty-five minutes; but for the first five and the last ten minutes it was a mere drizzle, and I think that fully $\frac{95}{100}$ of the whole amount fell inside of thirty minutes. This would indicate a rate of about $2\frac{1}{4}$ inches per hour.

During the night of May 7th, 1882, a most remarkable rain storm oc-curred in southeastern Mississippi, on the line of the New Orleans and Northeastern Railroad, then in course of construction. The storm ex-tended from Meridian to an unknown distance southward, but it reached its greatest intensity between the present stations of Tuscanola and Eastabutchie in the Valley of Leaf River. As nearly as could be ascer-tained the storm continued about six hours, but it was only very violent for about four hours. With the exception of my own rain-gauge at Meridian, no accurate gaugings were obtainable. At Meridian the total rain-fall was $\frac{81}{100}$ inch. At Ellisville, the county seat of Jones County, a cylindrical tin can 8 inches deep, used by an assistant as an improvised rain-gauge, was filled, and overflowed an unknown amount. Rocky Creek, 2 miles south of Ellisville, with a drainage area of about 15 square miles, rose to a flood cross-section of about 4 700 square feet. Its velocity could not have been less than $3\frac{1}{2}$ feet per second, giving a dis-

charge of about 16 500 cubic feet per second.   If we estimate that two-thirds of the water falling flowed off the ground into the creek (the whole valley is open pine woods; soil a very sandy loam, covered at the time with thick grass about a foot high), we will find that a rain-fall of 2½ inches per hour was required to produce such a flood.   In Leaf River Valley, between the stations named above, the country is sparsely settled by a class of people not accustomed to making accurate observations, and it was difficult to obtain full and reliable information.   Pains were taken to get all the facts possible, and after making abundant allowance for exaggeration, I was forced to believe and report that not less than 16 inches of rain fell during the storm.   Without detailing the evidence that led me to this conclusion, I may mention a few facts obtained.   One of the most intelligent and reliable residents of the neighborhood stated that a coal oil barrel with the head out, standing in an open lot, which barrel he was certain was empty when the rain began, was fully half filled in the morning.   The small streams in the vicinity reached a flood volume which could not be accounted for with a rain-fall short of 4 inches per hour.   Near the edge of a gently sloping table-land, between two small streams, but above their flood level, green pine logs 30 inches in diameter were floated and moved from their beds.   Considering all the circumstances, I do not think it improbable that the rain-fall during the most violent part of the storm reached a rate of 5 inches per hour.

The paucity of records of excessive rain-falls is greatly to be deplored, and equally lamentable is the fact that no adequate effort is being made to supply the deficiency.   It will require, at best, almost a generation to collect the necessary mass of statistics from which the general laws and limitations of excessive rain-falls can be deduced.   Aside from a few chance and isolated observations, we are practically doing nothing in this field now.   The Signal Service Department of the Army is undoubtedly the proper agent for observing and collecting such data, but there seems to be no systematic effort in this direction, and out of all the Signal Service stations in the country, only one is equipped with a self-registering rain-gauge.   There are, I believe, a very small number of such instruments in the hands of amateur observers and institutions of learning throughout the United States, but if the records of these are published at all, they are not readily accessible to engineers. Without such automatically recording instruments satisfactory observations are not possible.   In using the ordinary rain-gauge for this purpose, the observer must always trust his judgment, more or less, as to the amount and duration of down-pours that may occur during a continued rain storm.   The Government should be urged to substitute such self-recording instruments for the ordinary rain-gauges at all its signal stations.   The instrument-maker who will bring out a reliable self-registering rain-gauge, the cost of which shall be within the reach of ordinary

amateur observers and engineers, will contribute largely toward securing the co-operation of private observers in this field. Such an instrument need not be perfectly exact as to time and quantity—if it gives results correct to the nearest $\frac{1}{10}$-inch of rain-fall and five minutes of time, it will serve all practical purposes.

Of almost equal importance to a knowledge of the maximum rate of precipitation in any locality is that of the frequency of recurrence of rain-falls of a given rate and amount; for even those engineers who think it necessary and wise economy to provide, in city sewerage, for the heaviest possible rain-falls, will admit that in railroad and highway practice it may be bad economy to design culverts to carry floods that only recur once in thirty or forty years. The fact that Captain Hoxie has been only able, in making a special study of the subject, to collect the meager data given in the table of excessive rain-falls in this paper, shows how very small is the available stock of information on the subject.

There are, doubtless, in existence, scattered about in the note-books of engineers and amateur observers, a great many other records of value, but they have never been collected together, and are not therefore available. The importance of the subject is sufficient to warrant the Society in taking some official action, not only in the matter of collecting such scattered records, but to urge on the Chief Signal Officer the importance of systematic attention to the collection of such data, and of using self-registering rain-gauges at every station.

While there is evidently no direct relation between the maximum rate of precipitation and the mean annual rain-fall of any place, it is probable that the former bears some rude ratio to the latter. In the absence of any facts to the contrary, it would not be reasonable to expect and provide for the same rate of precipitation in a region where the annual rain-fall is 30 inches as where it is 40 inches. And inasmuch as the engineer is often called on to design sewers and culverts in localities where the mean annual rain-fall is known, but where no records whatever of maximum rain-fall can be obtained, a rude approximation of that ratio may sometimes be useful. An inspection of the few records we have seems to indicate that the following empirical formula may be safely used:

$$r = \frac{R}{12}$$

where R = mean annual rain-fall in inches.

r = probable maximum rain-fall, in inches, for one hour.

MOUNTAIN RAILROAD CONSTRUCTION.

By WILLIAM BARCLAY PARSONS, M. Am. Soc. C. E.

Although the fallacy of the narrow gauge arguments advanced so vehemently a few years ago is now generally understood, still railroad men generally do not appreciate the fact that the same results in the way of light construction, sharp curves, and, of course, heavy gradients, can be obtained with a standard gauge railway almost as well as with a narrow gauge, and without the attending disadvantages.

To illustrate this the author presents a description of some extensions that were added to a system of lumber railways in Northwestern Pennsylvania, under his direction, during the past year. This system, which will aggregate about 70 miles, is intended to develop the fine hemlock forests of that region. Topographically the country is much broken, being intersected by a number of small streams, from which the hills rise abruptly. It became necessary, therefore, that each principal valley should have a line of railway with tram-road feeders from the several mills located on the branches. A rather large mileage for the territory to be served was therefore required, on which account it was necessary to keep the expense of construction as low as possible. The heavy timbering and hardness of the material to be moved were constant obstacles to cheap work, while the ruling gradient in each case was rendered so very steep by the elevations to be overcome in

short distances that no breaking of gradient line was permissible, and therefore heavy work in rough places could be avoided or lightened only by the introduction of sharp reversed curves.

To illustrate the alignment and work, a small portion of the profile and map of one of the main stems is shown. (See Plate XV.) This particular line was 7 miles long, running up one valley, crossing the summit, and then down a stream on the other side a total distance of 7 miles, although 2½ miles are to be added as a future extension.

From the bottom, where connection was made with an existing track, to the summit was 3.64 miles, with difference in elevation of 606 feet. A compensation of 0.03 was decided on, so that the gradients on tangents worked out to be 3.316 per cent. or 175 feet per mile. The gradient as shown here was in favor of the traffic, but on the other side of the divide where the country was quite similar, a gradient of 3.182, compensated, had to be used against the loads.

The limit of curvature was put at 18 degrees, although once in heavy work on the other side of the hill, one curve of 19 degrees was laid out. As speed would under all circumstances be low, super-elevation could be kept down, and therefore a minimum length of tangent of 100 feet between curves was permitted, although in a few instances shorter tangents had to be used, the shortest being 77.1 feet between the 18-degree curves at station 135 as shown on the map.

Surveying of these lines was slow and expensive owing to the heavy timber. The difference of levels between summit and starting points was determined as closely as possible in the usual manner by aneroids, and then a trial preliminary run. It was afterward found much more expeditious to equip the chief of party with a light tripod-mounted compass provided with a telescope carrying a long bubble tube and vertical circle. By setting the circle at the gradient angle he laid out the preliminary in advance of the party, so that the axmen could clear the line of obstructing trees. Moreover, the line as thus staked closely approximated the actual grade line. Topography was accurately taken, plotted on a scale of 200 feet per inch, with 5-foot contours (or 100 feet per inch in rough places), the line of grade projected, and the railroad line fitted as closely to this as 18-degree curves would allow. On running this line in the field the changes required were but slight. In a heavily timbered country and where cost of work must be closely watched, the method of "paper" location is incomparably superior to field location,

which, under such conditions, at least, is little better than a good guess. The cost of engineering for location and construction, including running complete preliminaries on two different routes, was about $400 per mile. A large portion of this expense, however, was due to the number of axmen rendered necessary.

Cuts were made 16 feet wide, and fills 12 feet. The whole of the work being on side hill, which in many places was very steep, and in a wet country, much water had to be dealt with. Cross drain-boxes were used freely. Culverts under 4-foot banks were single or double wooden boxes 12 x 24 inches; under 10-foot banks, log culverts were adopted; while under banks over 10 feet, dry rubble culverts 2 x 3 feet, single or double, were built. There were on the 7 miles of the line, part of whose profile is shown, 75 271 cubic yards of material moved, of which 5 633 cubic yards, or 7.6 per cent. were solid rock; 8 298 cubic yards, or 11 per cent. loose rock; 26 468 cubic yards, or 35.2 per cent. tough clay where six picks were required for five shovels; and 34 872 cubic yards or 46.2 per cent. earth, most of which was heavy soil. The actual cost of labor, explosives and tools, including also feed and care of horses and mules for graduation, was $35 938.22, from which there is to be deducted a credit for value of tools left on hand of $750, so that net actual cost was $35 188.22. This covered: grubbing and clearing 51 acres; doing all the earthwork, including slope ditches; 467 cubic yards dry culvert masonry; sixty-eight wooden box and log culverts; and 2 424 feet of hemlock lumber for drain-boxes; in fact everything complete, ready for track, except trestles. This is an average of $5 026.89 per mile, or $0.465 per cubic yard of earthwork, without regard for classification, including, however, the cost of the sundry extras mentioned above; while the great percentage of rock and hard pan is to be borne in mind. The right of way was 50 feet wide, and as the fills and cuts were light, the proportion to be grubbed was great. This work, under such conditions, cost between $50 and $60 per acre.

In light work of this character, especially where the country is timbered so that roots interfere with continuous burrowing and where soil is heavy, there is great danger of underestimating cost of graduation. A generous allowance should be made to ordinarily prevailing contract figures.

The only available wood for trestles was hemlock, which cost from $7.50 to $8 per thousand feet. Large sticks were easily procured, and

on account of this and the low price it was possible to have the dimensions of the stringers greater than is usual with pine, in order to allow for the unreliability of hemlock. Bents were set 12 feet between centers. Posts and sills were 12 x 12 inch timbers, caps were 12 x 12 and 12 x 14, while stringers were single sticks, 12 x 18 inches. Bents were stayed laterally and longitudinally by 12 x 2 inch plank bracing. All members were secured by drift bolts. The bents stood on mud sills. 102 258 feet B. M. of hemlock were used, of which 13 704 feet were hewn from trees immediately adjacent to track. The sills and mudsills were generally made from this latter. About 1½ feet B. M. timber were used for each cubic yard of earthwork. Cost of labor per thousand feet for framing and erecting was $9.53, which included, however, expense of felling and hewing 1 142 lineal feet of timber, as mentioned above. Cost of bolts and spikes was twelve cents per lineal foot of trestle.

Average cost per mile of trestles, varying in height up to 28 feet:

12 650 feet B. M., at $7.75..........................	$98 04
163 lineal feet hewn timber. No charge.	
Bolts, spikes, etc................................	13 20
Labor, hewing, framing, erecting................	130 21
Total per mile...........................	$250 45

As to superstructure. The gauge was 4 feet 8½ inches. Rails weighed 40 pounds per yard, with angle bars. Joints were supported and broken. Ties were of hemlock, usual size, and spaced seventeen to a rail length. Split switches were used, with automatic switch stands, using the low target pattern, with weighted ground lever as the automatic device. The cost of 1 mile of such track was on last year's prices:

62.86 tons rails, at $33..........................	$2 074 38
352 joints complete, at $0.55...................	193 60
6 200 pounds spikes, at $0.225.................	139 50
3 000 cross-ties, at $0.15	450 00
Freight on materials	159 00
Track-laying	400 00
Total..................................	$3 416 48

The average cost per mile of the most expensive section which is represented by profile was:

Graduation.....................................	$5 026 89
Trestles.......................................	250 45
Track...	3 416 48
Engineering	400 00
Total...................................	$9 093 82

This represented the heaviest work and consequently most expensive line; on other lines where the topography was lighter the cost of graduation was lightened, so that the total cost per mile was reduced to about $6 500.   But these limits of figures furnished a railway, except as to unusual alignment and lightness of superstructure, standard in all respects.   With a limit of curvature of 10 or even 12 degrees, the building of these lines would not have been feasible.

The switch-back method of line development was used.   One switch-back was constructed on a gradient of 3.746 per cent. against traffic, and two more are laid out on projected lines.   Switch-backs for lumber roads have one great advantage, that they can generally be laid out near the head of the valley, with the effect of throwing the line down into the valley bottom, so that the timber can come down to the road.   They also serve as safety switches on steep gradients.

The motive power consisted of two forms of locomotives.   One a patented machine called a "Shay Gear" locomotive (see Plate XVI.), and the other an ordinary Mogul.   These Shay gear engines have three cylinders set vertically and together on one side of the boiler, just ahead of the cab.   They connect with a shaft which runs the whole length of the engine and tender, and is geared by bevel-gearing to every wheel. Between each wheel or pair of wheels is an articulated joint in the shaft, so that the length of rigid wheel base is that of an ordinary bogie truck. The great advantage obtained is that the whole weight of engine and tender is utilized for traction, and distributed over a much greater length of track than is the tractive weight of an ordinary locomotive.   The incidental advantages are short wheel base and high piston speed. These engines are therefore adapted to slow speeds, steep gradients and sharp curves.   The disadvantages are the enforced low speed and those attending such mechanical devices.

These engines are manufactured to weigh from 20 000 to 180 000 pounds, all of which is utilized for traction, and with two cylinders 7 x 7 inches for the smallest size, to three 16 x 15 inches for the largest. The maximum rigid wheel base is 56 inches.   The gearing ratio is slightly more than two to one.

The dimensions of the engines on the road in question were:

Eng. No.	Weight.	Cylinders.	Size Drivers.
2	120 000 pounds.	3–14 x 12 inches.	12–32 inches.
4	56 000 "	3–10 x 10 "	8–28 "
5	70 000 "	3–11 x 10 "	8–29½ "

A view of one of the Shay locomotives, built for another line, is shown.

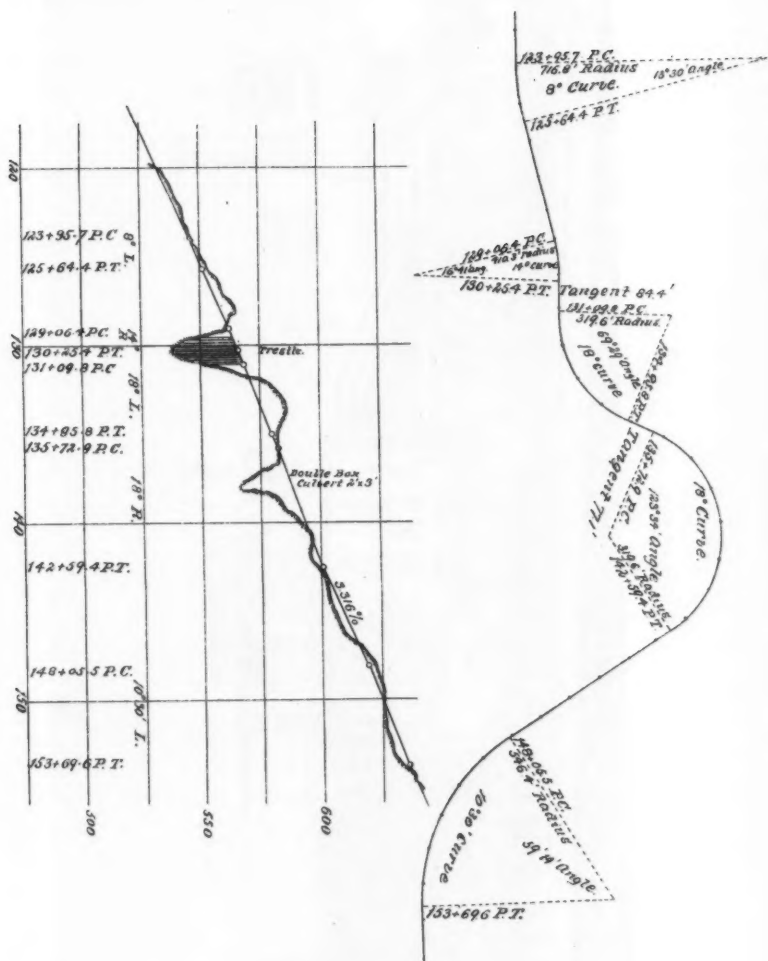The fourth engine in service is an ordinary Mogul of the following dimensions:

Weight of engine, 70 300 pounds; weight on drivers, 61 200 pounds; three 4-foot drivers on each side. Length of rigid wheel base, 10 feet; cylinders, 15 x 24 inches. This engine is in constant service and finds no difficulty in working around the sharp curves, showing that a special form of engine is not necessary for such alignment as described.

As a proof of this, and to show what strain a light track if built with care can resist, the following incident attests. The Mogul engine with seven loaded cars of lumber started down the 3.316 per cent. gradient illustrated. But the brakes were defective and the train immediately passed beyond the trainmen's control. The engine and cars ran down the hill 3½ miles, and through the reverse curves without damage to themselves or track. On passing the junction of the new track with the old line the combination of a flat curve out of line and a sag in the grade threw one car off the rails, when all the cars capsized, the engine, however, remaining on the track.

The author does not advocate the use of sharp curves or light rails, but cites the construction and operation of this road to show that under proper restrictions sharper curves and lighter rails can be used than is generally supposed, and so render possible the construction of railways that would not be feasible if the ordinary limits of curvature and super-structure were enforced. Speed is much more destructive to track than weight, and the constantly increasing weight of rails is rendered necessary more by the increase in speed of trains than by that in the weight of the locomotives. If speeds are kept low a light weight of rail will be found serviceable.

In the construction of such railways as much (or even more) engineering skill will be required as in the building of more pretentious lines. Every foot of the alignment must be carefully studied, and every item of expenditure rigidly considered, so that the construction becomes a connected series of small detail problems.

123+95.7 P.C.
125+64.4 P.T.
129+06.4 P.C.
130+25.4 P.T.
131+09.9 P.C.
134+85.8 P.T.
135+72.9 P.C.
142+59.4 P.T.
148+05.5 P.C.
153+69.6 P.T.

8° L.

18° L.

18° R.

10° 30' L.

Trestle.

Double Box
Culvert 2'x3'

3.316%

123+95.7 P.C.
716.8' Radius
8° Curve.
125+64.4 P.T.
13°30'0'angle.

129+06.4 P.C.
910.8'radius
16° curve
16°15'29'angle
130+25.4 P.T. Tangent 84.4'
131+09.9 P.C.
319.6'Radius
18° Curve.
Tangent 711'

18° Curve.

148+05.5 P.C.
316.4 Radius
10°30'Curve.
153+69.6 P.T.